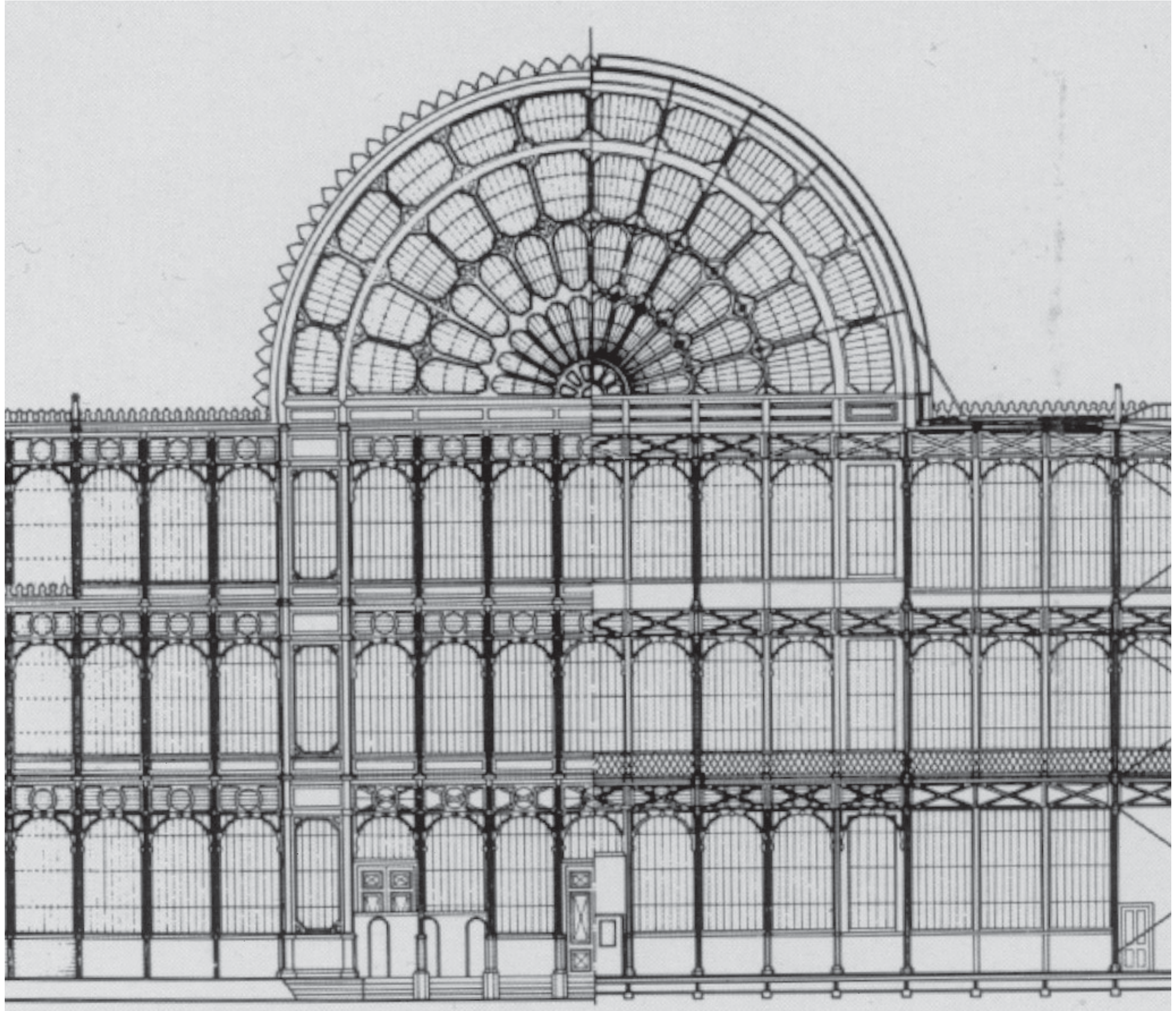

Paxton's Experimental Glasshouse at Hyde Park

by Henrik Schoenefeldt

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SYNOPSIS

Contemporary records show that the temporary building for the 1851 Great Exhibition at Hyde Park, based on a design by the horticulturist and glasshouse designer Joseph Paxton, represented a pioneering effort to appropriate the horticultural glasshouse for human occupation.[2] The objective behind Paxton's design, apart from exploiting the modular construction systems and mechanised production processes previously developed to surmount the excessive cost and labor associated with glasshouse construction, was to appropriate the climate and lighting conditions inside the exhibition building to the specific environmental requirements of the exhibition.

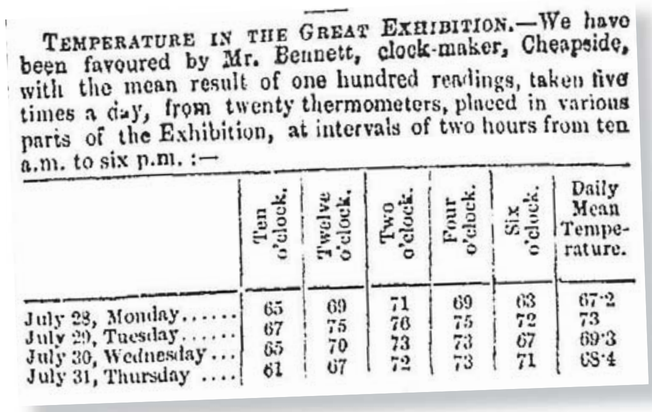
The project correspondence reveals that the Royal Commissioner's decision to adopt

Paxton's design in favour of the Building Committee's scheme was significantly influenced by the successful reconciliation of important functional aspects, in particular lighting, ventilation and the control of humidity and temperature. In extensive disputes among members of the Royal Commission and various committees the Building Committee was fiercely criticised for having failed to address these issues in their own design.[3]

For Paxton, analogous to the design of horticultural glasshouses – where the manufacture of artificial climates for the nurturing and preservation of tender plants was the chief design objective – the guarantee of adequate environmental conditions for the display and preservation of artifacts and for the comfort of the building users was a critical functional aspect of the exhibition building. While the executed building was clearly the outcome of Paxton's successful collaboration with the contractors, suppliers and structural engineers, contemporary sources reveal that the design builds extensively on Paxton's experience with the design, construction and the environmental performance of horticultural glasshouses.[4] The contractors and engineers admitted that they were highly dependent on Paxton's specialist knowledge and experience as a glasshouse designer, in particular in terms of the detailing of the glass envelope and the control of the indoor environment.[5]

Commentaries in the contemporary press reveal that Paxton's idea of adopting a glasshouse as a model for the exhibition building was widely criticised as a very risky and untested design experiment. Referring to the Palm House at Kew and the Conservatory at Regent's Park as examples, prospective exhibitors and critics in the media warned that success of the building depended on the facility to successfully manage the interior environmental conditions, a prerequisite for protecting vulnerable exhibits from exposure to excessive sunlight, heat and humidity, as well as for ensuring the comfort and health of staff and visitors during the period of the exhibition.[6]

Paxton, however, stressed that his idea was not without precedent, but that it was informed by his extensive experience with managing the environment inside glasshouses, and referred to a number of his earlier conservatories as precedent cases which provided evidence of the feasibility of his proposition.[7] Contemporary horticultural literature, which contains detailed accounts of the working methods, design criteria and issues underlying Paxton's experimentation with glasshouses in the period 1833-50, illustrates that the glazing employed at Hyde Park was the outcome of extensive experiments with glazing systems which Paxton had conducted to improve the environmental performance of glasshouses.



TEMPERATURE IN THE GREAT EXHIBITION.—We have been favoured by Mr. Bennett, clock-maker, Cheapside, with the mean result of one hundred readings, taken five times a day, from twenty thermometers, placed in various parts of the Exhibition, at intervals of two hours from ten a.m. to six p.m. :—

	Ten o'clock.	Twelve o'clock.	Two o'clock.	Four o'clock.	Six o'clock.	Daily Mean Temperature.
July 28, Monday......	65	69	71	69	63	67·2
July 29, Tuesday......	67	75	76	75	72	73
July 30, Wednesday...	65	70	73	73	67	69·3
July 31, Thursday	61	67	72	73	71	68·4

Figure 1. Sample of Temperature readings published in the Morning Chronicle 1st August 1851 (Image: CU Library).

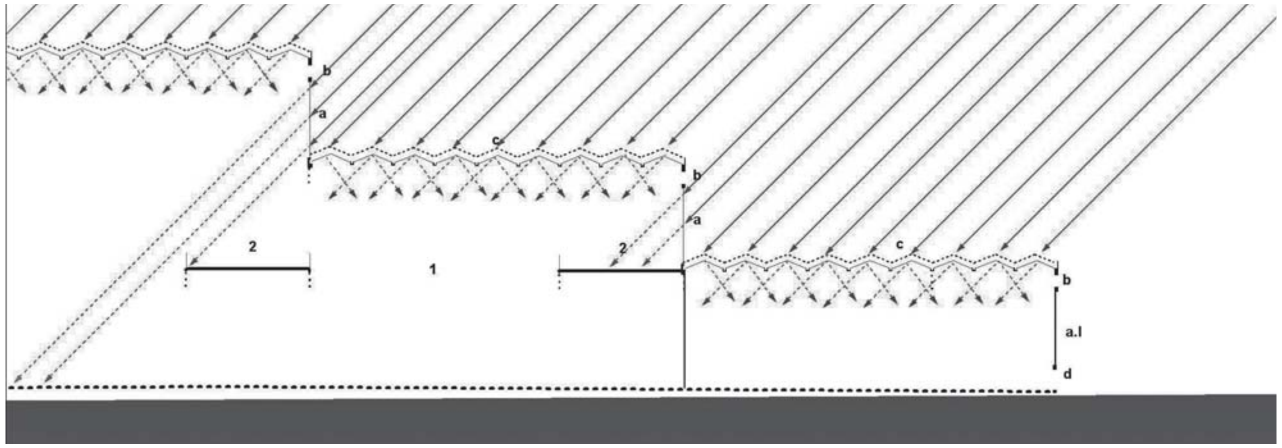


Figure 2. Cross section.
Key: a. Vertical boarding b. Top Ventilators c. Ridge & furrow glazing with external canvas shading d. low level ventilators 1. Light Court, 2. Galleries.

Paxton's chief objective was to improve the performance of glass envelopes in terms of weather tightness, internal condensation and heat conservation.[8] The development of this innovative glazing technology represented a first step towards appropriating the glasshouses environmentally for the purpose of an exhibition building. Although Paxton had conducted a small-scale experiment to demonstrate the effectiveness of his ventilation and passive cooling strategy, the Executive Committee remained sceptical and requested that the temperature inside the building, like in horticultural glasshouses, be systematically monitored and recorded.[9] Large parts of the temperature data, collected during the period of the exhibition between May and October 1851, were published in various newspapers *(fig. 1)*.[10]

The anxiety among the public and the Executive Committee was not unjustified, since the environmental design issues at Hyde Park, in particular the issue of cooling, which was required to keep the interior temperatures at comfortable levels for human beings during the summer, had no precedent in horticulture.[11] Furthermore, Paxton proposed an entirely passive system of environmental control, constituting of shading, evaporative cooling and natural ventilation, which, apart from the small-scale demonstration at Chatsworth, had not been tested before.

The objective at Hyde Park was to keep the interior atmosphere not only very dry but also to maintain low interior temperatures during periods of excessive heat in the summer.[12] A detailed study by the author of the environmental design objectives and strategy underlying Paxton's design, which can only be discussed very briefly in this article, was the subject of an MPhil Dissertation and a recent journal article by the author published in *Architectural Research Quarterly*.[13]

This article goes on to discuss the post-occupancy history of the building, revealing the process by which the environment inside the Crystal Palace was monitored, and how the ventilation system of the building was retrospectively modified to improve its performance. It reveals that Paxton and the Executive committee were confronted with the serious difficulties of making fully glazed structures climatically suitable for human purposes. The finding of Paxton's pioneering experiment at Hyde Park, however, had a significant influence on the design of the Crystal Palace at Sydenham, which has to be understood as a second step in Paxton's effort to transform the horticultural glass-house prototype into an environmental design model for architecture.

PAXTON'S ENVIRONMENTAL DESIGN STRATEGY AND OBJECTIVES

An overarching environmental design strategy, as contemporary sources illustrate, had been an integral and important part of the design from the very beginning.[14] The aim was to provide good lighting conditions for the display of the exhibits 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.[15] A very brief summary of Paxton's environmental design objectives and strategy is given in the following two sections.

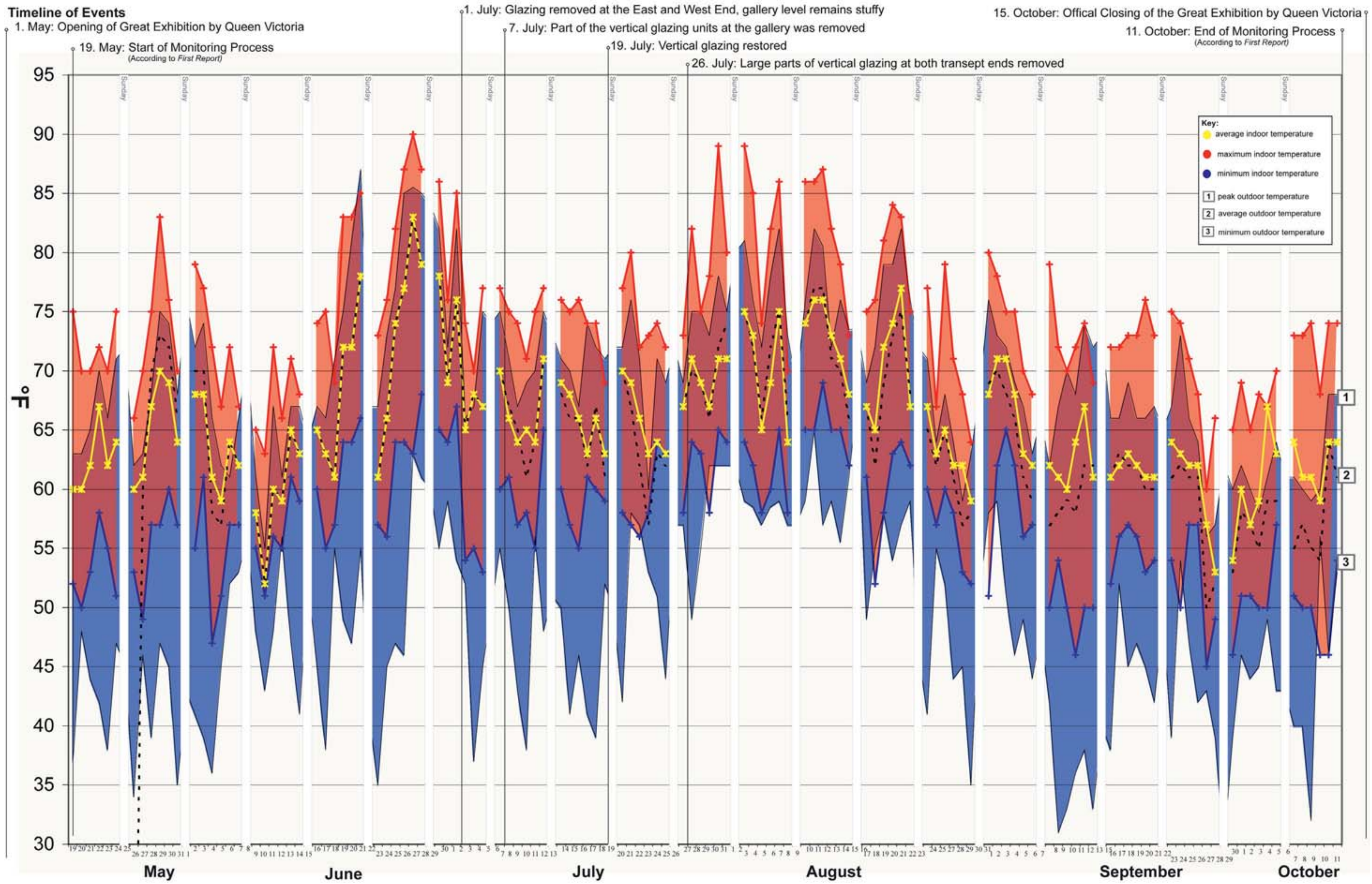
LIGHTING CONTROL

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.[16] 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. 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.[17]

In order to subdue the intense sunlight, the entire horizontal part of the ridge and furrow roof was covered with translucent calico screens, so that the interior was illuminated by a relatively uniform diffused top light *(fig. 2)*.[18] 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 24 feet in depth. Since the daylight regime limited the extent to which multiple floors 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

Figure 3. Maximum, Minmum and Average Indoor and Exterior Temperatures recorded by the Royal Miners and Sappers between May and October 1851

Source: Graph Compiled by author based on data published in the *First Report* [average outdoor and indoor temperature + maximum and minimum indoor temperature] and the *Gardener´s Chronicle and Agricultural Gazette* between 24th May and 18th October 1851 [maximum and minimum outdoor temerature]



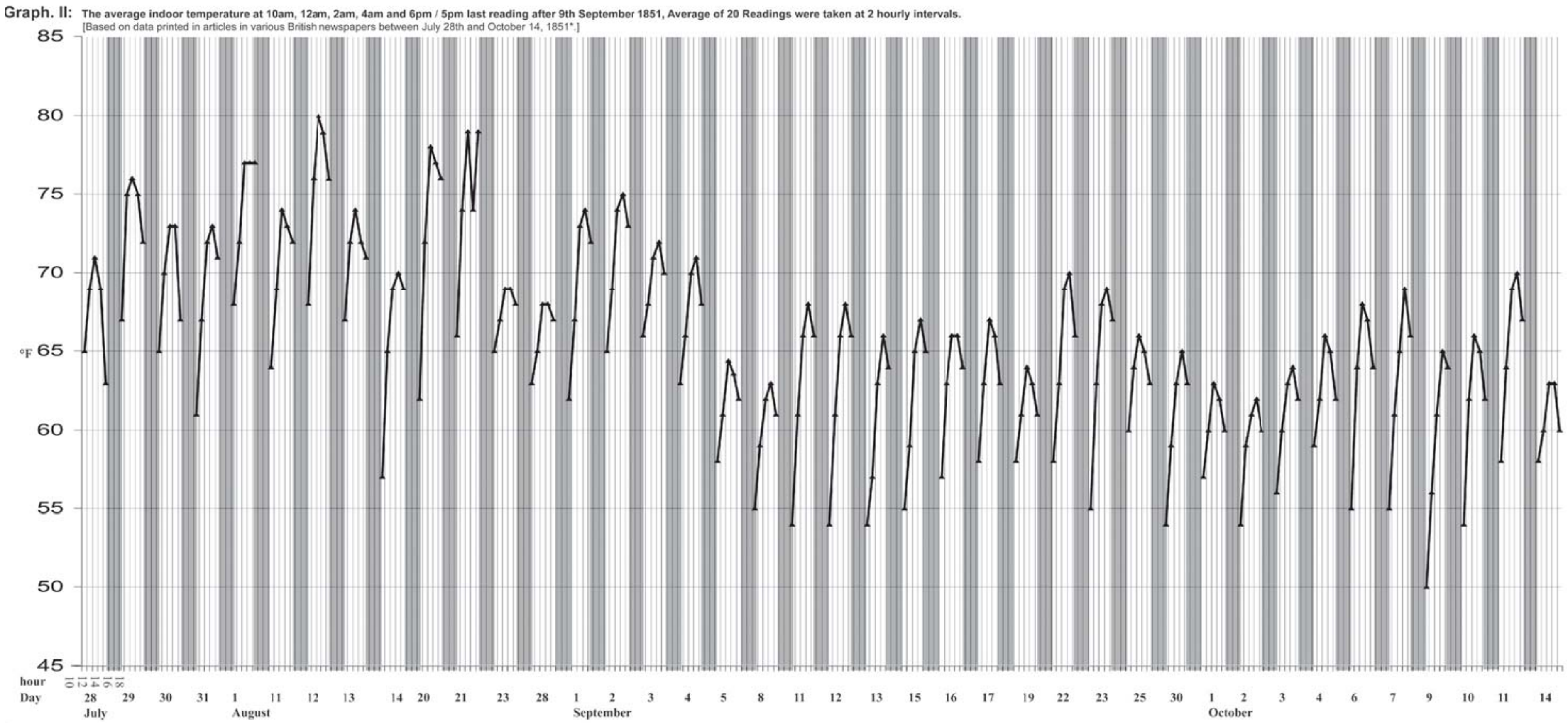
tiers of diminishing width, forming the shape of a stepped pyramid in cross section.

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.[19] 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.[20] 300 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.[21] 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 *(fig. 3)*.[22]

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 to further reduce solar gains, and internal punkha fans, large sheets of canvas that were made to move up and down to expose visitors to an artificial breeze.[23] Aware that ventilation and shading alone were 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 moisturised to cool down the incoming air stream by evaporation.[24]

Figure 4. Average Temperature recorded at two hourly intervals on a selected number of days.



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 *(fig. 4)* and a summary of this post-occupancy study was included in the First Report of the Commissioners of the Great Exhibition.[25] This appears to be one of the first systematic post-occupancy studies ever conducted inside a building for non-horticultural use. Horticultural glasshouses were monitored, in some cases sporadically, in others systematically, to ensure that vulnerable foreign plants were kept in an adequate artificial climate.[26] 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.

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, 40 thermometers were installed throughout the interior on

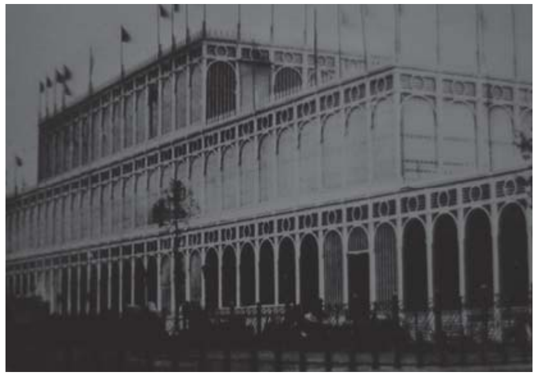


Figure 5. View of East elevation, showing two of the ventilators that had been retrofitteed ith retractable canvas screens (Image: London Metropolitan Archives).

two levels of the building by a thermometer maker named Mr Bennet of Cheapside, although no information was given on their exact position.[27] The Royal Sappers and Miners, who were responsible for regulating the ventilation, monitored and kept register of the interior temperature.[28] Between 19th May and 14th October readings were taken daily from each of fourteen thermometers at two hourly intervals between 9 am and 6pm except from the period after the 9th September when the last reading was taken at 5pm. Three additional thermometers were installed outside the building to monitor the corresponding external temperature.[29]

HISTORICAL CLIMATE DATA COLLECTED INSIDE THE CRYSTAL PALACE

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, forming the basis of a reconstruction of the actual environmental conditions that occurred inside the building.[30] The First Report included a summary and a brief analysis of the post-occupancy study, listing the daily maximum, minimum and average indoor temperatures (based on 56 readings) and daily average external temperature (based on 12 readings) recorded between 19th May and 11th October 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 18th June and October 14th 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.[31] The following section is a reconstruction and analysis of the building's environmental performance based on the temperature records discussed above.

THE ENVIRONMENTAL HISTORY OF THE GREAT EXHIBITION BUILDING AND ITS ANALYSIS

On the 27th 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 unprecedentedly high temperatures inside the building: 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 of the Crystal Palace, with a maximum air temperature of 97°F in the afternoon and a daily average of 78.7°F.[32] 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.[33] 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 2nd July *(fig. 5)*, with the intention of reducing the indoor temperature and 'to secure a refreshing thorough draught from end to end of the interior.'[34] It reported that it lowered the indoor temperature at ground level, but hot and stuffy air continued to accumulate at the upper part of the building.[35] To improve the climate at gallery level parts of the glazing in the north and south galleries were removed on 7th July. It resulted in a more uniform temperature across both levels. Around the 19th 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.[36] The problematic temperatures reported between 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, followed by a period with notably lower indoor temperatures, ranging between 70-80°F. In the second period, occurring between the 1st and 22nd August, the peak indoor temperature exceeded 80°F on fourteen days.

Considered in the whole the measurements demonstrate that the temperature inside the Crystal Palace was highly variable both across the day and between individual days. On 2nd June the indoor temperature ranged between 47°F and 78°F and on the 1st August the average indoor temperature rose from 68°F at 10am, to 72°F at noon, peaking at 77°F at 2pm, which prevailed until 6pm.[37] Strong temperature variations between daily average temperatures were recorded, for example in the period between 22nd August and 3rd September. The average indoor temperature dropped from 73°F on 22nd August to 58°F on 30th August, but rose to 69°F on 3rd September.

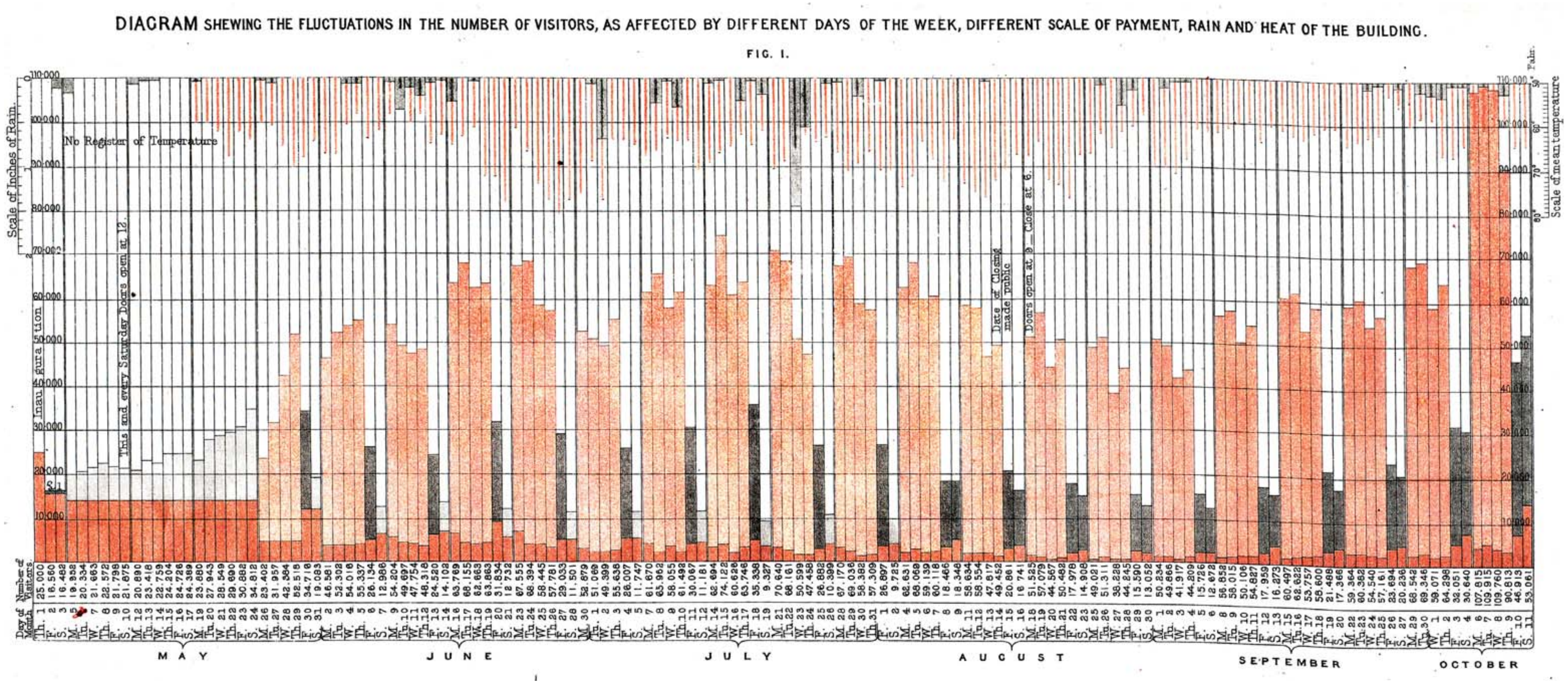
The peak indoor temperature consistently exceeded the peak outdoor temperature by a minimum of 2°F and a maximum of 15°F, demonstrating that the shading and ventilation strategy employed was not sufficient to prevent the indoor temperature from exceeding the outdoor temperature, the aim of Paxton's original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

FIRST REPORT OF THE COMMISSIONERS

The First Report of the Commissioners, published in April 1852, illustrates 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 19th May and 11th October. It shows 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 the average internal temperature was recorded to be between 1-4°F lower than the corresponding external temperature on 26 days only.[38]

The report also included a chart comparing the daily number of visitors with the daily mean indoor temperature *(fig. 6)*. It concluded that variations in the number of visitors inside the building had only had a marginal effect on the indoor temperature. It reported: '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 0.85 degrees.'[39] 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 partitions on the ground floor along the north elevation that were obstructing the air flow in the building. In order to compensate for the restricted airflow 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.'[40]

Figure 6. Graph showing visitor numbers and corresponding daily indoor peak temperatures (Image: First Report, British Library).



CONCLUSION

This paper has shown that aspirations to maintain ideal lighting conditions for the display of artifacts, 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 a pioneering experiment on adopting a large scale 'glasshouse' for exclusively human purposes. To achieve these objectives a completely passive environmental design strategy was proposed, and the building management conducted a post-occupancy study during the opening hours of the Exhibition to objectively evaluate its thermal performance. Various contemporary newspapers report that excessive temperatures, humidity and reduced levels of oxygen had occurred inside the building over extended periods of time and had lead to complaints by staff and visitors about discomfort, drowsiness and headaches.[41]
In response to these issues the management took measures, with some effect, to improve the ventilation. This included the temporary removal of glazing units and the installation of operable canvas screens.[42] A statistical analysis of the data, and an inquiry into the building's problematic performance and its causes, was subject of a final post-occupancy study included in the Commissioner's First Report.[43] The inquiry into the appropriating of glasshouses for human occupation, which started at Hyde Park, continued after the exhibition. Contemporary records show that Paxton had critically re-evaluated his own design and had made several proposals for a second prototype.[44] This was finally realised in his design for the Crystal Palace at Sydenham, the subject of the author's current research.

(ENDNOTES)

1 The main body of this paper is a reproduction of a short paper read by the author at the PLEA Conference 2008: 'The Building of the Great Exhibition of 1851. Environmental Design Experiment', in Kenny, P., Brophy, V. and J.O. Lewis (eds), Proceedings of the 25th Passive and Low Energy Architecture International Conference, School of Architecture, Landscape and Civil Engineering, University College Dublin (2008).

2 The author's work is based on extensive archival research. Apart from the study of contemporary Journals and Newspapers, the author studied contemporary source material, such as diaries, letters, drawings, reports and photographs held at Chatsworth, the British Library, the Metropolitan Archives, the National Art Library and the RIBA Drawing Collection at the Victoria and Albert Museum, National Archives, Archives of the Royal Commission of 1851, Imperial College, and the Archives at the Royal Botanic Gardens Kew.

3 Memorandum on the Advantages of Paxton's Plan, dated 4th July 1850, and Francis Fuller's diary, held at the Victoria and Albert Museum.

4 While Robert Mallet emphasised the contribution of the contractors and engineers towards the resolution of structural issues, extensive reports in the contemporary Architecture and Engineering Journal illustrate that the resolution of the environmental design issues was equally important to making the use of a glass structure feasible for an exhibition building: Mallet, R., 'The Record of the International Exhibition', William Mackenzie, Glasgow, Edinburgh, London (1862), p. 60.

5 'Public Dinner at Derby to Mr. Paxton', The Times (7th August 1851), p. 8.

6 The Times (15th July 1850); 'National Exhibition Building', Architect and Building Gazette (20th July 1850), p. 344; 'Building for the Exhibition of 1851', Builder (27th July, 1850), p. 358; An Architect, 'Exhibition Of 1851', The Times, (17th July, 1850), p. 8.

7 Anonymous, 'The Palace of Industry: a brief history of its origin and progress, with a descriptive account of the most interesting portions of the machinery employed in its construction', Illustrated London News (16th November 1850), p. 385.

8 Detailed Accounts of Paxton's glasshouse experiments were published in the Gardener's Chronicle, Paxton's Magazine of Botany, Horticultural Register, and Loudon's Gardener's Magazine.

9 Henry Cole's Diary (1850); The Times (29th March 1851), p. 5; Illustrated London News (16th November 1850), p. 385.

10 Large quantities of data was published by The Times, Daily News, Morning Chronicle and the Illustrated London News.

11 Illustrated London News (16th November 1850), p. 385.

12 Detailed accounts of his environmental design objectives and strategy were given by Paxton in various lectures between August 1850 and August 1851.

13 Schoenefeldt, H., 'The Crystal Palace - Environmentally Considered' in Architectural Research Quarterly (2008), pp. 283-94; (2007).

14 'Memorandum', Illustrated London News (6th July 1850).

15 Gardener's Magazine, v. 9, pp. 303-317.

16 The Times, 14th November 1850, p. 4.

17 Downes, C., The Building for the Great Exhibition of the Works of Industry of All Nations, John Weale, London (1851) pp. 39-41.

18 Paxton, J., 'The Victoria Regia House, Chatsworth', Civil Engineer and Architect´s Journal (October 1850), p. 324.

19 Illustrated London News, (16th November, 1850), p. 386.

20 Commissioners of the Exhibition of 1851, First Report of the Commissioners for the Exhibition of 1851, London (1852), pp. 67-89.

21 Anonymous, The Palace of Industries, John Olivier, London (1851).

22 Commissioners of the Exhibition of 1851 (1852), pp. 67-89.

23 Illustrated London News (6th July, 1850), p. 13; 'Exhibition of 1851, Monthly Report of Progress', Journal of Design and Manufactures (1850), pp. 29-32.

24 Illustrated London News (16th November, 1850), p. 386.

25 Commissioners of the Exhibition of 1851 (1852), pp. 67-89.

26 Gardener´s Magazine, v. 9, pp. 303-317.

27 The Times (16th September 1851), p. 5, The Times (29th March, 1851), p. 5.

28 Commissioners of the Exhibition of 1851 (1852), pp. 67-89.

29 Ibid.

30 Ibid.

31 Gardener´s Chronicle, May 24th 1851, p. 328 to Gardener´s Chronicle, October 18th 1851, p. 664.

32 Times, September 16th, 1851, p. 5.

33 Times, June 30th, 1851, p. 5. & Times, July 1st, 1851, p. 5.

34 Times, September 16th, 1851, p. 5. & Times, June 27th, 1851, p. 5.

35 Times, July 1st, 1851, p. 5 & Illustrated London News, October 11th, 1851, p. 471.

36 Illustrated London News, October 11th, 1851, p. 471.

37 Times, August 2nd, 1851, p. 5.

38 Commissioners of the Exhibition of 1851 (1852), pp. 67-89.

39 Commissioners of the Exhibition of 1851 (1852), pp. 67-89.

40 Commissioners of the Exhibition of 1851 (1852), pp. 67-89.

41 Numerous accounts of people's perception of the environmental conditions inside the building were published in The Times, Examiner, Daily News, Morning Chronicle.

42 The Times (27th June, 1851), p. 5; Illustrated London News (11th October, 1851), p. 471; The Times (1st July 1851), p. 5.

43 Commissioners of the Exhibition of 1851 (1852), p. 67.

44 Accounts of Paxton's proposal were given in various, interviews, pamphlets, letters, newspapers and journals between summer 1851 and spring 1852.