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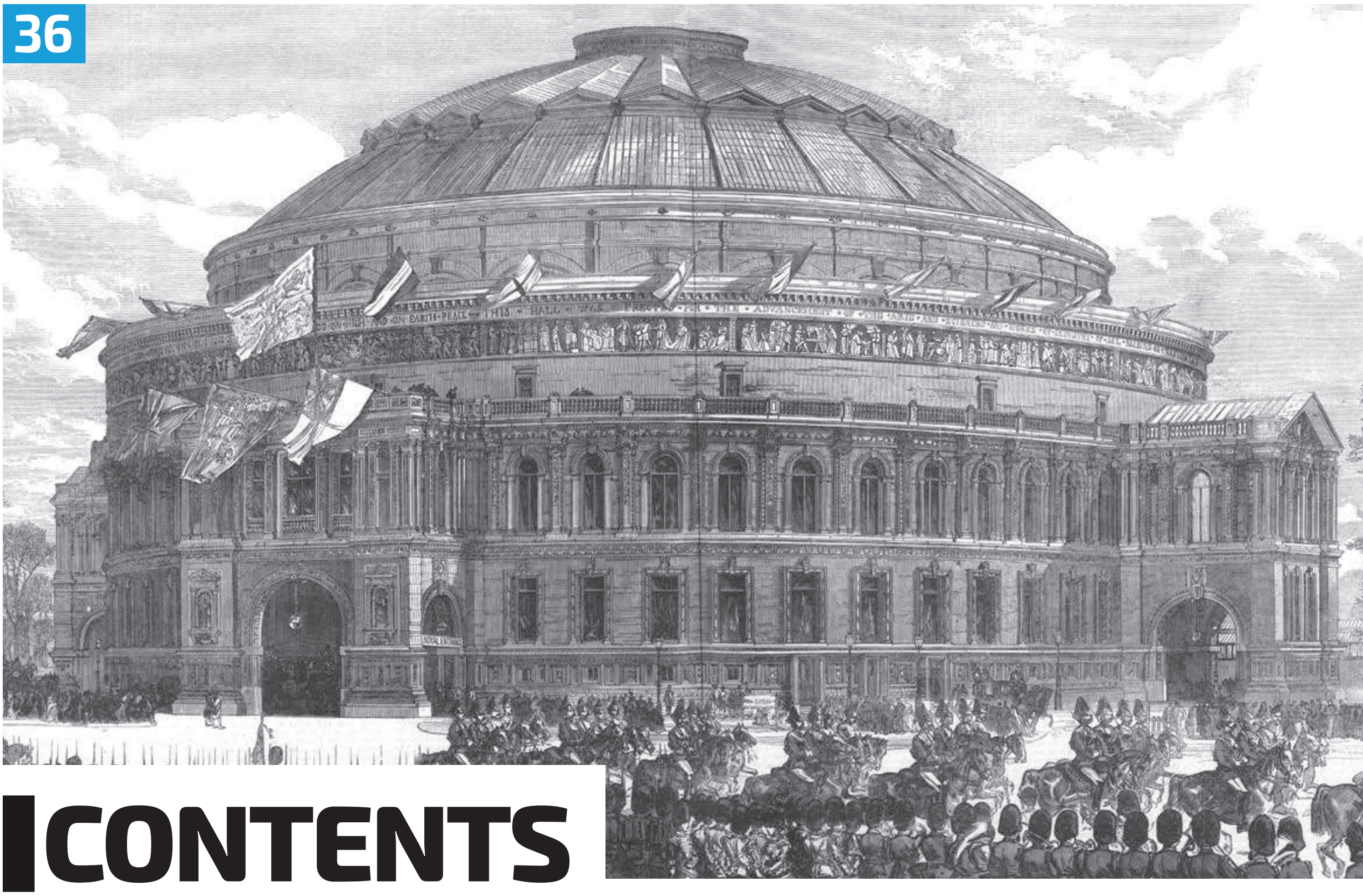

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THE ROYAL STANDARD

Ventilating the Royal Albert Hall's huge auditorium was one of the great challenges of 19th century services engineering. **Henrik Schoenefeldt** and **Maria Köhler,** of the University of Kent, describe how the great Victorian engineers achieved the feat

The idea to build a 'Central Hall of Arts and Sciences', was first proposed by Queen Victoria's beloved consort, Prince Albert, after the Great Exhibition of 1851 – but he was never to see his vision become a reality.

Albert's untimely death in 1861 saw the ambitious project shelved until 1865 when the Prince of Wales – later King Edward VII – appointed a committee to revive the scheme.

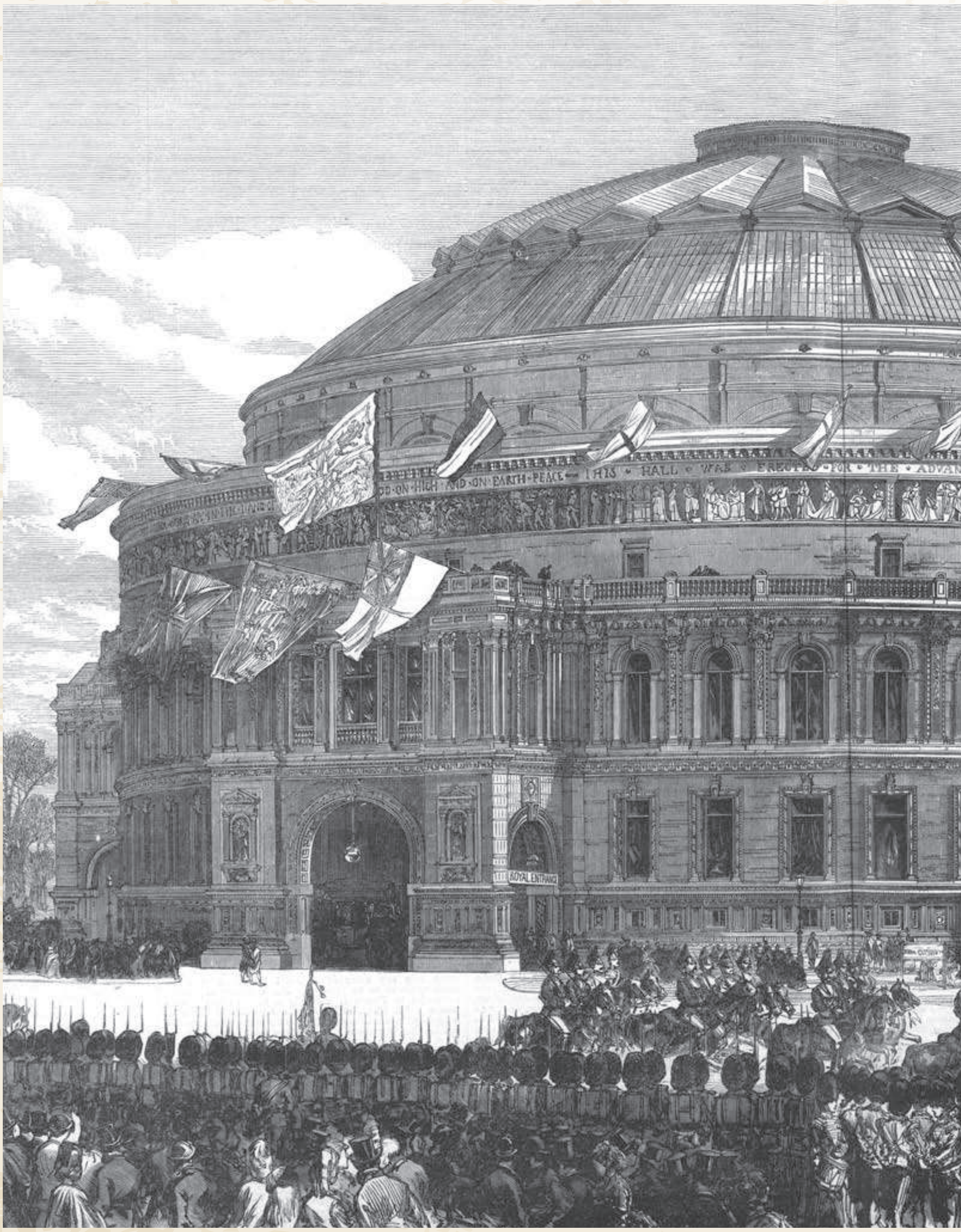
The building received its now familiar name – Royal Albert Hall – in 1867, when a still grieving Victoria renamed it in honour of her late husband, at a ceremony to mark the laying of the foundation stone.

The Prince of Wales's committee comprised the prince himself and a group of architects and engineers. These included Lt Colonel Henry Scott of the Royal Engineers, the man who later became responsible for the design and the execution of the building.

A concert hall, based on the form of the Roman Colosseum, was first developed by Francis Fowke, a captain in the Royal Engineers, but he died with his plans incomplete, leaving Scott to finish and adapt the original design.

Ventilation and climate control were a challenge in his creation – a vast space measuring 185ft by 219ft and 135ft high (56.4m by 66.8m by 41.1m high) that could accommodate audiences of up to 8,000. Like many theatres of the time, maintaining adequate ventilation and preventing overheating were most challenging.

Civil engineer Wilson Weatherly Phipson[1] was appointed in 1869 to design the warming and ventilation system under Scott's direction. Phipson's scheme was a hybrid, following principles developed by Belgian engineer Englebert-Theophile Van Hecke. The system combined a fan-driven air supply with a



thermally driven extract system. The hot air was exhausted through a circular shaft above the central oculus in the ceiling. This shaft ended in a lantern above the roof and was equipped with manually adjustable louvres that allowed attendants to regulate the outgoing flow. Air was extracted using the natural stack effect assisted by the waste heat of more than 9,000 gas burners fixed around the oculus. Scott wrote that the buoyancy 'exerts an enormous force,' in particular when the space was heated during the winter months, or the gaslights were in use.

Fresh air, introduced with the aid of two large fans driven by a 5hp (3.7kW) steam engine, underwent a process of heating and humidification before it entered the hall. Phipson stressed that the Van Hecke system allowed for the creation of uniform climatic conditions[2].

These principles were not new, but the challenge was applying them to a very large and tall space. The original plans show that an extensive network of air chambers was created inside the basement for the distribution and conditioning of supply air. It was composed of three concentric air chambers. A large, oval plenum chamber was situated below the central arena, followed by an inner and outer ring of linear chambers. These followed the curve of the main walls.

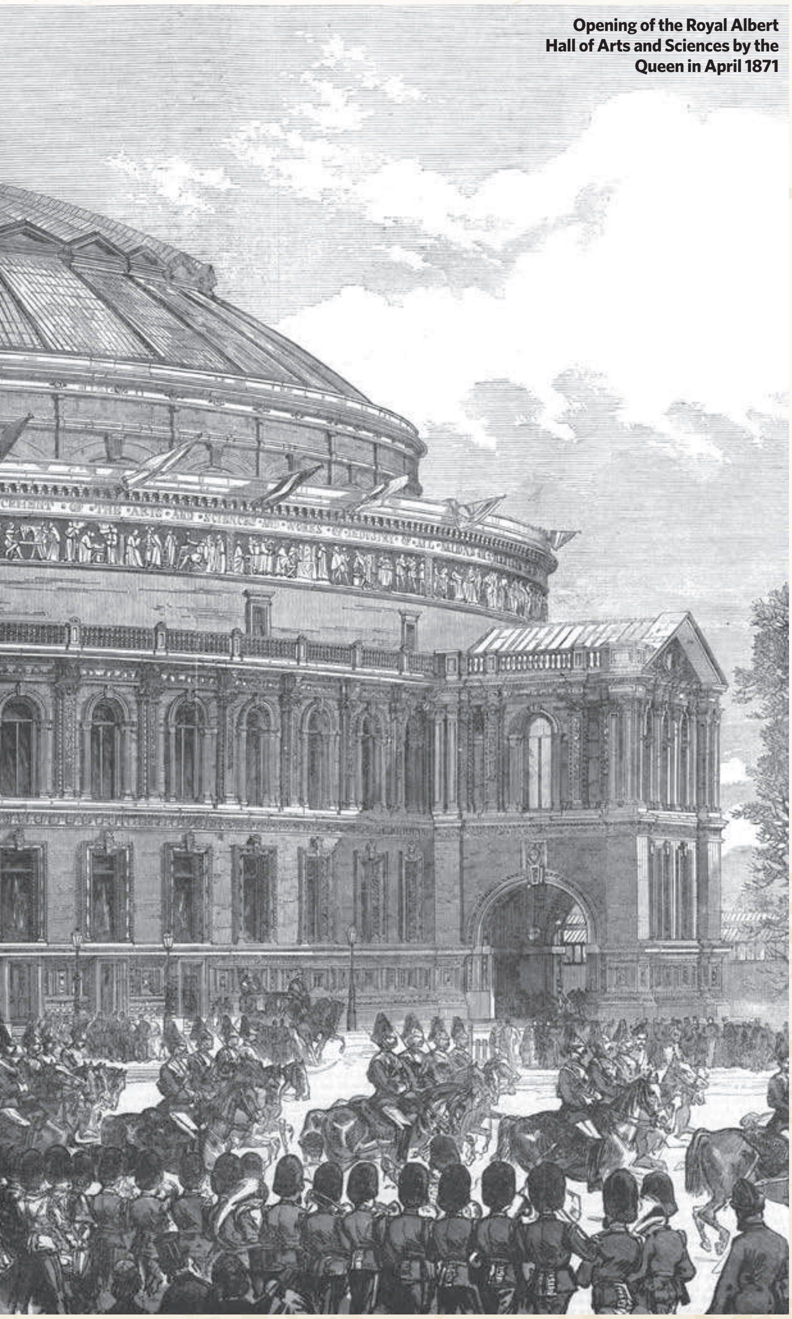
Ventilation was introduced at a relatively late stage in the design development. Despite the potential risk of technical solutions being constrained and compromised by existing plans, the late arrival of the building services engineer in architectural projects was not uncommon. It was the case in many Victorian public buildings renowned for their complex environmental systems, such as the Natural History Museum, Royal Courts of Justice and the Houses of Parliament.

The air was forced into the basement chambers through two shafts at the south end of the hall, using two large, steam-powered fans 6ft (1.8m) in diameter. The supply was divided into two – one inlet supplying the chambers on the eastern side, and the other on the western side of the oval plan.

The air first entered the outer ring of chambers, which in the original drawings is referred to as the 'main heating chamber'. It supplied warm air for the boxes, corridors and function rooms, but was also linked to the central plenum of the arena. It was connected to this through four cross-channels, two on the north and south end, respectively, and to the inner ring via four shorter cross-channels.

The inner ring was used to supply air to the amphitheatre seats surrounding the central arena. The cross-channels had valves to adjust the quantity of air conveyed to the plenums below the arena or amphitheatre stalls, respectively. The shorter cross-channels permitted attendants working the system to continue the supply to the amphitheatre seats over periods when that to the arena was closed. Phipson wrote that the valves also allowed the supply in certain sections to be closed off or to concentrate it in one area.

The main heating chamber was also linked to an array of vertical shafts to convey tempered air upwards to the spaces surrounding the main hall, such as the boxes, corridors and various function rooms. Each of



Opening of the Royal Albert Hall of Arts and Sciences by the Queen in April 1871

RESEARCH AIDS BUILDING CONSERVATION

This article is based on research conducted in the context of the module *AR828 – Rediscovery – Understanding Historic Buildings and past Environmental Technologies,* which forms part of the University of Kent's MSc in Architecture and Sustainable Environment.

The module was developed by Dr Schoenefeldt with the aim of formally embedding the study of historic environmental principles and technologies within the teaching of building science. The aim is that this should better inform building conservation practice.

The material used in such research included drawings, letters, records of historic measurements, scientific reports and past engineering literature. Research topics ranged from 18th-century principles of daylight design and early solar thermal technology to the ventilation of French hospitals and the history of mixed-mode ventilation.

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The 135ft high hall could accommodate audiences of up to 8,000

Phipson's specifications	
Winter temperature	Hall & rooms: 55°F to 58°F (12.8°C to 14.4°C). Corridors, stairs, porches: 52°F to 55°F (11.1°C to 12.8°C).
Summer temperature	During hottest days interior to be kept below the exterior air temperature.
Humidity	Wet bulb thermometer not to exceed dry bulb thermometer by 10°F (5.6K).
Ventilation rate	3,600,000ft^3 per hour (28.3m^3 per second).

Phipson specified control regimes and pre-conditioning the hall before performances

» the larger rooms above the entrance porches were served by two fresh-air shafts. These had separate valves to adjust the supply to every room or box individually.

The outer and inner ring of heating chambers were filled with hot water coils and 'moistening tanks' to raise the temperature and humidity of the supply air. The system followed the principle of a warm air central heating system – a technology that had already been well-established since 1830. The temperature in the hall was boosted by warming the supply air, but it also incorporated arrangements for cooling, humidification and air filtration.

It followed a method of air conditioning developed during the 1830s and 40s. The air was heated using hot-water condensing boilers. Water running through cast-iron pipes was heated by steam supplied via a central boiler house, containing three boilers producing 25 hp (18.6kW). The heating was divided into 16 sections, each of which could be operated separately, according to demand in different parts of the hall.

Phipson paid close attention to the operational dimension of the system. In the original 1869 contract, he gave detailed specifications for the system, which included references to monitoring and control procedures and a 12-month post-occupancy evaluation period, to allow the system to be tested and fine-tuned.

The hall was equipped with an array of scientific instruments to monitor the condition of the air, which included hygrometers, thermometers and anemometers. A self-acting valve with anemometers was installed near the input fans to monitor and control the amount of fresh air passing into the basement passages. Phipson specified separate control regimes for summer and winter and gave instructions to pre-condition the hall in preparation for concerts.

Records relating to the performance of the system show that Phipson's concern about operational procedures was justified. In his paper, Scott stressed that the performance of the system was heavily reliant on the diligence of the staff responsible for the operating and monitoring procedures[3]. One of the operational challenges was synchronising the fan-driven supply with the buoyancy-driven extract. Scott reported instances where the pull of the shaft had caused inward draughts every time the doors leading into the hall were opened. To prevent air pressure in the chamber becoming lower than outdoors, the louvres of the shaft had to be adjusted to regain a balance.

"The system followed the principle of a warm air central heating system – well established since 1830"

Overheating posed the most significant challenge, both in winter and summer, as the large audiences – up to 8,000 people – represented a substantial heat load. Phipson reported that the body heat of these crowds, combined with the gaslights, caused the temperature to rise by around 4.5K during performances. Before a concert, the hall was warmed to a moderate temperature, but by the time 8,000 people were seated it had already increased by just over 2K. Anticipating the effect of thermal stratification at different levels of the hall, Phipson asked attendants to supply cooler air at the upper levels. While some cooling was provided by spraying the incoming air with cold water, and by circulating cold water through the hot-water coils, the ventilation was central to preventing overheating. Phipson specified a supply of 3,600,000ft^3 per hour (28.3m^3 per second), but the amount introduced was adjusted depending on the size of audience and indoor temperature.

While higher ventilation rates were able to reduce the rise in air temperatures or renew the atmosphere, it also exposed the audience and performers to increased draughts rising through the floor. In his specification, Phipson acknowledges the importance of positioning inlets at a distance from people to protect the audience from the cooling effect of air currents. Because of the high density of people seated within the arena and stalls, however, this was not achievable. They were sited immediately above the main air inlets for the hall, exposing the audience to uncomfortable draughts from below, if the ventilation rate was high. The fresh air for the main auditorium was supplied through gaps between the boards covering the arena floor and via apertures in the risers of the raked seats inside the stalls.

For staff, daily balancing the requirements of ventilation and thermal comfort of Prince Albert's grand vision was a constant challenge. **CJ**

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