A SILENT PERFORMANCE AT CARNEGIE HALL

The client insisted that the new air-conditioning system for the acoustically and visually splendid hall be noiseless and invisible. The engineers complied.

Almost a century after its original opening, Carnegie Hall has made a stunning second debut. Ever since Tchaikovsky conducted the first performance there in 1891, the legendary New York City concert hall has been in constant use. Not only has it withstood the wear and tear of enthusiastic music lovers and the normal depredations of time, but it has suffered abuse as well. Retail stores were built at street level during the Depression, and in 1946, when a movie about Carnegie Hall was made, a large section of the shell above the stage was chopped away. In 1960, it was threatened with destruction and was rescued only at the eleventh hour.

In 1979, the architectural firm of James Stewart Polshek and Partners submitted a master plan to the Board of Directors for the refurbishment of Carnegie Hall. Under the plan, they proposed to renovate the main hall; replace deteriorated and inefficient building systems; improve the safety of the building and make it easier to move around in, especially for the handicapped and elderly; improve the quality of the public areas; create new areas for artists' use; and renew the exterior. This ambitious restoration took five years and fifty million dollars to carry out. Its completion was celebrated on December 15, 1986 with a gala concert, and has been praised by audiences and critics.

The task of installing a new air-conditioning system fell to engineers at Goldman, Sokolow, Copeland, P.C., who worked under the supervision of Martin J. Goldman, the partner in charge of the project. The firm has been involved in the restoration of such historic buildings as City Center and the Old Custom House in Manhattan, the Brooklyn Academy of Music and the Brooklyn Museum, and the Frontier Festival Theater and the State Capitol Building, both in Albany.

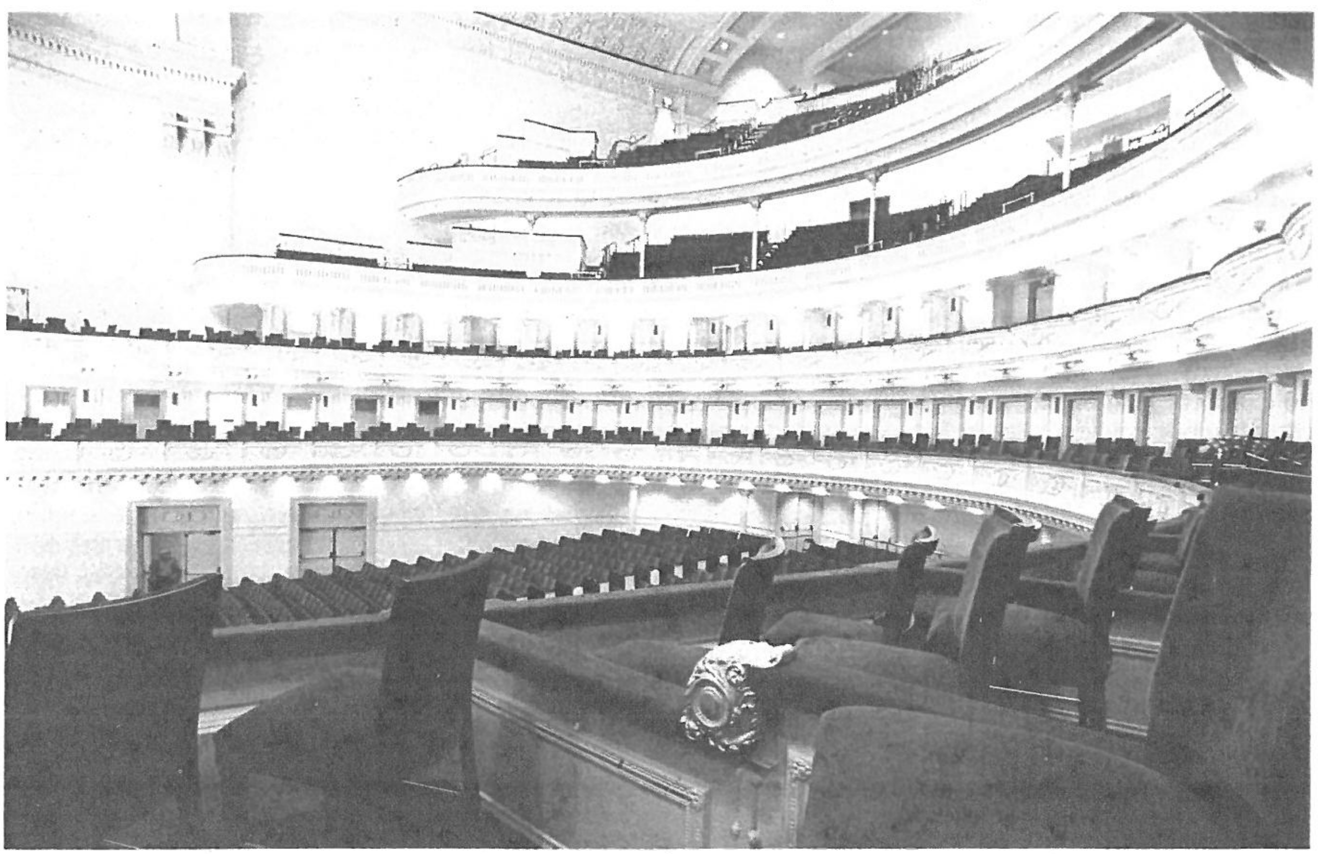
The Carnegie Hall job was a challenge. Not only was it necessary to install new equipment and large ductwork in existing—small—spaces, but the equipment had to operate without transmitting any noise into the hall itself. In addition, because the plans specified that no visible changes be made in the hall, the air had to circulate through existing outlets.

"We were confronted with *psychoacoustics,*" said Jack Karbiner, project manager for GSC. The acoustics at Carnegie Hall were considered among the best in the world and the Board knew that audiences and critics would be listening carefully for changes in the renovated space. "If they *saw* that something had been altered, they would be psychologically prepared to *hear* a difference," explained Karbiner.

RESTORING A MASTERPIECE

Carnegie Hall, which stands at the corner of 57th Street and Seventh Avenue, is actually three brick and terra-cotta structures, built between 1891 and 1896. Aside from the main performance space, which seats 2816, it has three additional halls, including a movie theater and a recital hall. The original architect, William Burnet Tuthill, designed the building after carefully studying hundreds of other concert halls. Very little scientific literature about architectural acoustics existed in those days, but modern analysts say that the four-foot–thick walls, 18-foot–deep masonry floor, 35-foot–deep foundation walls, and

Air-delivery troffers and the large ducts they require are concealed in the ceiling of the main hall. The 2816 seats are divided into the following sections: parquet (bottom), first-tier boxes, second-tier boxes, dress circle, lower balcony, and upper balcony.



View from a first-tier box along one side of the hall. To supplement the air handlers in the basement, a second mechanical equipment room was built above the second-tier boxes and below the dress circle, at the back of the hall.

other, plaster, walls all contributed to the excellence of the sound at Carnegie Hall.

In his initial survey of the building systems, Karbiner discovered huge ice racks in the basement—remnants of the original "air conditioners." Four large fans had been used to propel air across the ice and into the hall, cooling at least some of the audience. Mechanical air conditioning was not installed until 1947, and then its purpose was only to compensate for the heat generated by the lights and the audience. It was not designed to overcome the temperature of a summer night in New York, and the hall remained closed during July and August. When it was saved from destruction in 1960 by the efforts of violinist Isaac Stern and other loyal fans, Carnegie Hall stood in need of a complete overhaul of its air-conditioning system.

NEW AIR IN SMALL SPACES

The first three phases of the restoration project included the partial replacement of the plumbing, air-conditioning, and electrical systems, and took place between 1982 and 1985. Work on the building systems was completed during the fourth phase, from May to December of 1986, during which time the building was closed.

In 1983, a new chilled-water plant was installed in the sub-basement, and large air handlers were put in the basement to feed air into the main hall. Because space was limited, packaged air handlers would have been impractical. The engineers designed a custom air-handling system that included special features such as duct-sound attenuators, acoustic barriers, and vibration isolators. The acoustician, Abraham Melzer of the Israeli firm of Melzer and Partners, was satisfied that the new air-handling system had no significant impact on noise levels in the hall.

Karbiner describes the earlier, air-handling, phase of the project as "replacing the heart" of the system. "The 1986 phase, when we extended the air conditioning to the tiers and balconies, was like replacing the arteries." The earlier phase was relatively straightforward, since all the existing systems were exposed in the basements. When it came time to redesign the air-distribution systems, however, no one knew for sure what was behind the walls and ceilings. "There were no as-built drawings," according to Karbiner. Although line drawings from 1947 existed, they were not helpful in deciding how the design should be carried out. "We opened up the walls during construction, and often we had to redesign on the spot. There were steel and cross bracing where no one had anticipated them. We also discovered that a good deal of the air-conditioning ductwork had not been installed according to the drawings."

It quickly became clear to the engineers that there was no room to install the large distribution ducts specified by the acoustician. These were important because, even if noise from the air-handling equipment is completely attenuated, air moving through the ducts will hiss and rumble unless it moves very slowly and the ducts are unusually large. The solution was to install a second mechanical equipment room, which would distribute air to the dress circle, the center seats of the first and second tiers, and the rear of the parquet section; the basement air handlers would serve the remaining sections. A new mezzanine level was built for the equipment room above the second-tier bathrooms and below the dress-circle lounge—an acoustically critical location, since one side of the room would abut the hall itself.

ISOLATING NOISE

Noise criterion curves are used to measure levels of background noise caused by HVAC systems. A good concert hall has an NC rating of between 20 and 22; by way of comparison, a good recording studio has a rating of 18 and an office building rates between 35 and 40. The acoustician specified an NC rating for Carnegie Hall of 20 to 22 when all the mechanical equipment is running at full capacity. For recording sessions, equipment can be turned down so as to achieve an even lower level of background noise.

Other factors that affect the acoustics are poorly installed ductwork, partly closed dampers, missing or torn acoustic duct lining, and imperfectly balanced equipment. Some of these problems cannot be controlled by the design engineer, and in order to ensure a margin for error, GSC designed the air-conditioning system to meet an NC rating of 15. Two heavy-density walls with air space between them isolate the equipment room from the hall.

SILENCING THE AIR

Controlling air-borne noise presented a different set of problems. Air is less noisy if it moves slowly, and the acoustician specified duct velocities ranging from 316 to 1100 feet per minute. The velocity of air in an office building, in comparison, is often as high as 1500 feet per minute. Here again, GSC designed the system to come well within the specifications. Duct velocities range from 165 feet per minute in some of the branch ducts to a maximum of 1100 in the outside, acoustically separated ducts.

All the air leaving or returning to the air-conditioning units passes through sound attenuators before entering the main hall. Ten-foot–long attenuators were selected after their effectiveness in each of eight octave bands, from 63 to 8000 cycles per second, was matched with the sound characteristics of the air-conditioning units in the same octave bands. Because the air-conditioning outlets were only three feet from the wall of the equipment room, it was necessary to run the attenuators not horizontally into the hall, but vertically in a shaft through the dress circle, under the balcony seats, and back down again. Sound attenuation was actually increased because of all the bends in this circuitous route.

The entire length of the ductwork is lined with a two-inch layer of fiberglass. This represents a departure from common practice, in which ducts are lined with an inch of acoustic material for a distance of about twenty-five feet from a fan or air conditioner. The material was chosen for its strength as well as its acoustical qualities. The airstream surface is coated with a matte-finished resin to resist erosion and deterioration. Both glue and pins were used in applying the fiberglass, to help prevent it from coming loose. The sheet-metal fasteners used on the ducts were carefully chosen to hold tight, not rattle, and take up a minimum amount of space.

DRESSED-UP AIR

The Board of Directors insisted that renovation of the hall must preserve its original appearance. This meant that the outlets through which the air entered the hall must look as they

With its new air-conditioning system installed, Carnegie Hall will be able to operate year-round for the first time.

always had. Wall registers for the first- and second-tier boxes and ceiling diffusers at the back of the parquet and dress circle were replaced with outlets of similar size and appearance, and air was directed down through decorative slots at the edge of the ceiling in the main hall.

These outlets were not enough for even half the required air supply, however. The heat generated by new, high-wattage theater lights, and the fact that Carnegie Hall will now be open twelve months a year, mean that the amount of air-conditioned air required will be twice what was called for in the 1947 plans. The challenge of circulating additional air without changing the appearance of the hall was met by designing troffers to deliver air through slots that already existed in the ceiling. The original purpose of these slots is unclear; they may have been exhaust ports or they may have been simply decorative. In any case, they were ideally located; there was plenty of room in the ceiling for both the troffers and the large ducts they required.

This system was also designed to be much quieter than specified by the acoustician. It has a noise criterion rating of twelve, a full six points below the required minimum. Branch ducts to the 38 troffers are isolated from the trunk ducts with flexible connections; the troffers are attached to the ceiling with angle irons and sheet-metal screws and then sealed with wire mesh and vermiculite plaster. Air directed into the ceiling cools the heat from the lights before it can enter the hall.

AIR ON STAGE

Restoration of the stage shell removed in 1946 meant new ductwork and air outlets were needed on stage. The stage has its own air-conditioning system, which, because of the new lighting, must provide more air than before.

Although there was room for a larger air-conditioner in the stage equipment room, there was not enough room to install a ten-foot sound attenuator horizontally. The floor of the room above the equipment room was demolished, and the attenuator was installed vertically. Air travels up through a five-foot–long, twenty-five-square-foot sound attenuator, through two ninety-degree bends, and down another, identical, attenuator, which is separated from the first one and from the air conditioner by an acoustic wall. The air is then directed horizontally into large, acoustically lined ducts, and emerges on stage through six outlets, each ten feet square.

What you don't hear is as important in a concert hall as what you do hear. Audiences and performers will appreciate the pains taken to provide a silent air-circulation system. ■