ASHRAE Historical Archive December 22, 2007

Documentation of 1920's Carbon Dioxide Air Conditioning System
Orpheum Theater, Minneapolis Minnesota

Documented by Bernard Nagengast, Consultant, ASHRAE Historical Committee
Assisted by Richard Hermans Dave Marietta and William Murray

Site visit August 29, 2006

Backround:

I was contacted in 2002 by Mr. Lee Blaske who was interested in some history on a carbon dioxide air conditioning system installed at the Orpheum Theater in Minneapolis, Minnesota. I mentioned the installation to W. Stephen Comstock at ASHRAE and we decided that it would be of value to document the system. I also told William Murray, ASHRAE Regional Historian, about the system. Due to time constraints nothing further was done until now, when Bill Murray mentioned to me that a renovation was being done to the mechanical system at the theater, and that it might be prudent to pursue any documentation of the system since some of the original mechanical equipment was to be removed. Transportation expenses to Minneapolis were authorized by ASHRAE and I met with Bill Murray in Minneapolis to visit the theater site.

Visit details:

On August 29, 2006, I met with William Murray (Regional Historian), Richard Hermans (Senior Project Manager, Center for Energy and Environment) (Figure 1) and Dave Marietta (Orpheum Theater Operations Coordinator) (Figure 2) to inspect and photograph the original HVAC equipment at the theater. The visit was completed that day.
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Fig 1 Rick Hermans (left) and Bill Murray (right)

Fig 2 Dave Marietta

Fig 3

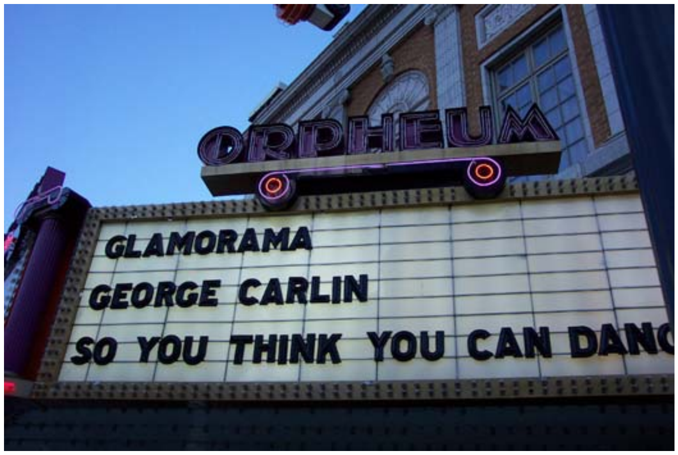

Fig 4

History:

The Orpheum Theater (Figures 3, 4) was opened in 1921, located on Hennepin Anenue at 9th Street, Minneapolis, Minnesota. The seating capacity was 2741. (Figure 4A) The building architect was Kirchoff & Rose. The mechanical contractor is unknown to Historic Theater Group LLC, the current theater operators.

The building's indoor environment was maintained using three separate systems, two small ones for the box office and front lobby areas (figures 5, 6, 7), and a large main system for the auditorium and other rooms. (This report concerns the main system only.)

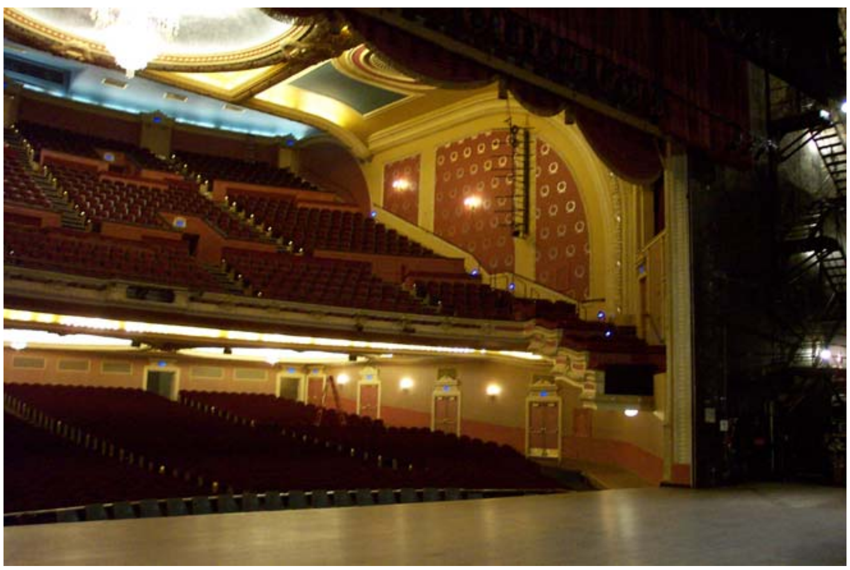

Fig 4A Auditorium of Orpheum Theater

Fig 5 Lobby of Orpheum Theater. Note return air grilles above arch.

Fig 6 Lobby of Orpheum Theater

Figure 7 Lobby of Orpheum Theater

The main HVAC system was a combination system, using heated and cooled air and also direct radiation. General air conditioning and heating was of the plenum type using two supply (main floor and balcony) (Fig 8) and one return centrifugal fans with supply air distribution under the auditorium seats and conventional diffusers in areas desired to be conditioned. Cast iron pin type heating surface was located in the supply air streams. Direct steam radiation was used for supplemental heat in the auditorium and lobby and for about 30 individual dressing rooms on six floors. The steam was originally supplied from on-site boilers.

Fig 8 Rick Hermans and Bill Murray at main supply air fan

The theater was air conditioned using a carbon dioxide direct expansion prime surface refrigeration system manufactured by Wittenmeier Machinery Company. Power was supplied by a DC Electric Motor. (Fig 9) The system used an air washer for filtering and cast iron steam heating surface located in the air stream for general heating.

Two stationary engineers were employed to operate and maintain the mechanical plant.

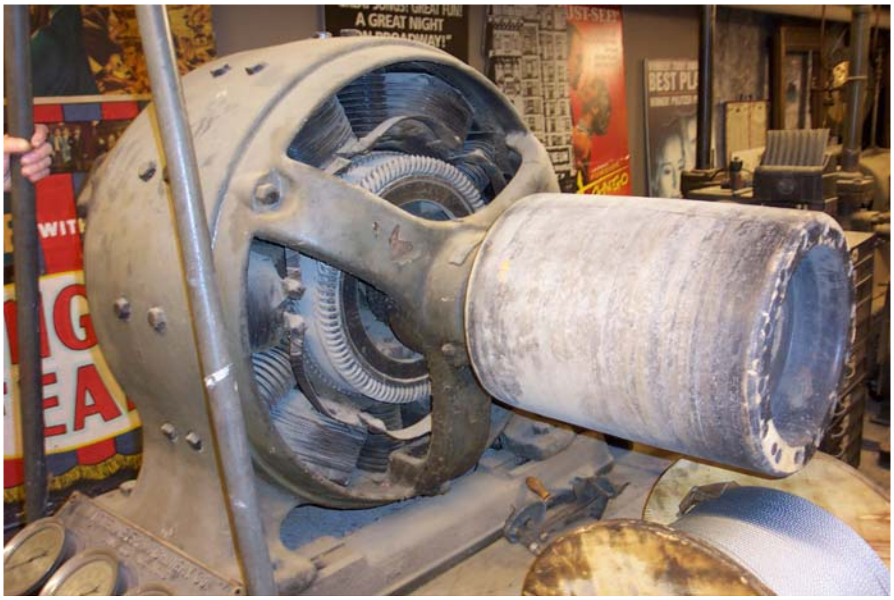

Fig 9 100 HP DC motor for CO2 Compressor.

The original system was in use until 1952, when the carbon dioxide compressor was taken out of service. This was done because the electric power company ceased distribution of Direct Current electricity . (Previously the DC power was supplied from the St. Anthony Falls Hydroelectric Plant.) The power company offered to continue DC supply in limited amounts using on-site rectifiers and the Orpheum elected to continue DC power for the fans, pumps and lighting. The power company refused to provide rectified DC for the refrigeration compressor.

From 1952 to 1988, there was no comfort cooling per se. The air washer was used with the cool well water to temper the air in summer, providing very limited if any dehumidification. (Dave Marietta noted that one Broadway review from the period was titled “Tropical Camelot!”) In 1988, the air washer was taken out of service. Conventional fin coils were installed in the supply plenums for both the main floor and balcony supply fans. (Figure 10) Conventional media air filters were installed in the common return air duct. (Figure 11) The fin coils were cooled using chilled water supplied from a Carrier multistage rack chiller unit using four 30 HP semi-hermetic compressors. (Figure 12)

Figure 10 Rick Hermans between fin coils for heating and cooling, installed in 1988.

Figure 11 Rick Hermans and Dave Marietta in front of filter banks.

Fig 12 Carrier 120 HP Chiller installed in 1988

In 1992, a general restoration of the theater was done. (This included restoration of existing architecture plus some modification that was necessary to accommodate large scale modern live performances) The seating capacity was reduced from 2741 to 2618. As part of the restoration, the mechanical plant was modified. All direct current electrical apparatus and lights were taken out of service, replaced by AC. The steam boilers were removed, steam now being supplied using 250 PSI steam from the downtown district system. The high pressure steam was reduced to 5 PSI for the building. (Figure 13) For cooling, chilled water was utilized from the downtown district system. (Figure 14) The 1988 fin coils were left in place, the Carrier chiller was taken off line, and the district chilled water was used in the fin coils.

Since the mechanical system did not perform to expectations after 1992, a decision was made to re-commission the system in 2006 and modifications will be made to improve the system.

Fig 13 Steam reducing valves

Fig 14 Chilled water pipes (overhead) from downtown district system

On Site Observations of the main HVAC system :

Mechanical system air side

The HVAC system uses fancy grilles incorporated into the architectural design. The original air distribution is mostly intact. The system is typical of many early auditorium systems. (Figures 15, 16)

Fig 15 Return air grille

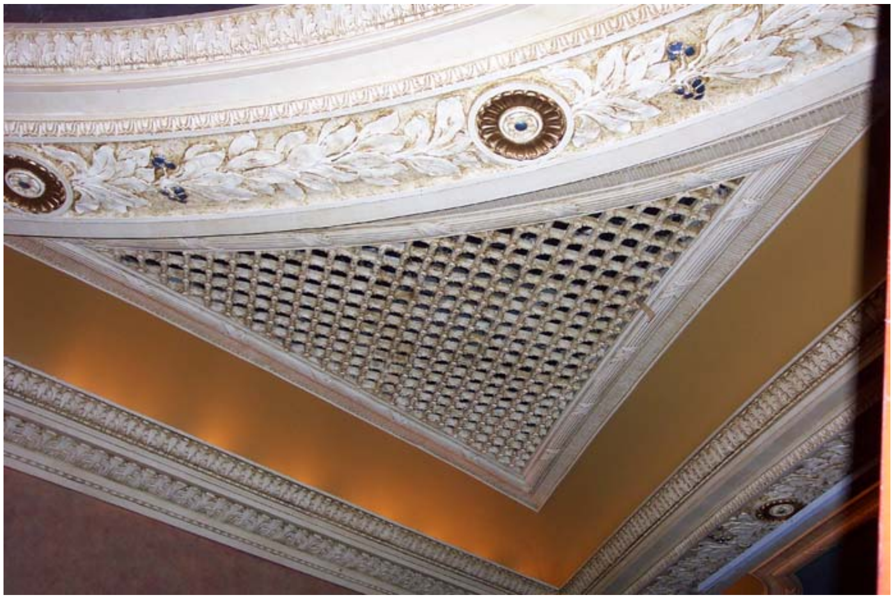
Fig 16 Return air grille

Conditioned air in the auditorium is supplied using plenums located under the main floor (plenum constructed of reinforced concrete) (Figures 16A and 16B) and the balcony floor (plenum constructed of clay block with lath plaster partitions that divided the plenum into 3 sections.) Each of these plenums has a fan.


Fig 16A View inside main supply air plenum.

Fig 16B Another view inside main supply air plenum.

Approximately 5 inch holes in the top of the plenums (Figure 17) connect to “mushroom ventilators” under the auditorium seats. These mushrooms, commonly used in theater and auditorium HVAC systems in the 20’s 30’s and named for their shape resembling a mushroom, supply conditioned air to the auditorium. (Figure 18)

Fig 17 5 inch opening in supply plenum for mushroom ventilator.

Fig 18 Mushroom ventilator for supply air under auditorium seats

The system uses a bottom-up distribution, the air flow proceeding from the floor to the ceiling return air grilles. (Figure 19) These grilles and other return ducts connect to the return air plenum located in the attic, over the auditorium ceiling. (Figures 20, 21) There is a fresh air inlet turret on the roof (Figure 22) connected through dampers (Figure 23) into the return plenum. The discharge of the return fan flows down to the basement where it splits to the main and balcony supply fans. A small portion of the return fan discharge is vented through a roof turret. (Figure 24)

Fig 19 Return air grille in auditorium ceiling


Fig 20 View inside return air plenum. Return air duct in back.


Fig 21 View inside return air plenum showing return air ducts.


Fig 22 Fresh air inlet on roof.


Fig 23 Fresh air inlet dampers in return air plenum. Old DC fan motor in foreground.

Fig 24 Exhaust air turret on roof.

There are two supply fans located in the basement, one for the main floor plenum (Figure 25) of the auditorium, and one for the balcony plenum. There is one return air fan in the attic, inside the return air plenum. (Figures 26, 27) The ducts and fan enclosures are constructed of heavy gauge steel sheeting. (Figures 28,29)

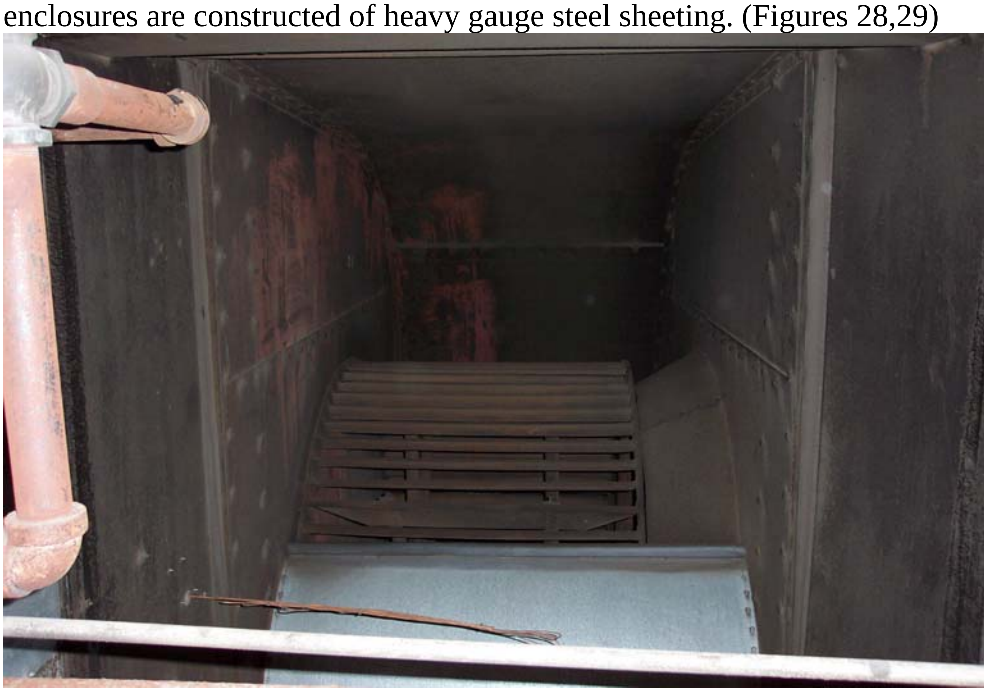

Fig 25 Supply air fan outlet.


Fig 26 75000 CFM return air fan


Fig 27 Bill Murray looking through return air fan cage.

Fig 28 Return air fan casing


Fig 29 Dave Marietta looking at original steel supply duct.

The fans were manufactured by the New York Blower Company, La Porte, Indiana. Operating speed varies between 143 and 277 RPM. The fans are slow enough that one can actually see the shaft key turning! The fans are extremely quiet, as originally designed for theater work. All three fans were originally operated by 25 HP direct current, wound rotor motors that were connected to the fans by flat leather belts. (Figure 30)

When the DC system was taken off line in the 1992 renovation, the DC motors were replaced with 60 HP AC three phase induction motors, mounted close to the fans, and the flat belts were replaced by V-belts. (Figure 31) At first, the new drive system was noisy, with a lot of belt squealing. Three change-outs of the pulleys were required to solve the problem, and even then, the fans could not be operated at full speed. The 1992 renovation called for 92000 CFM but no more than 60000 CFM was achieved.

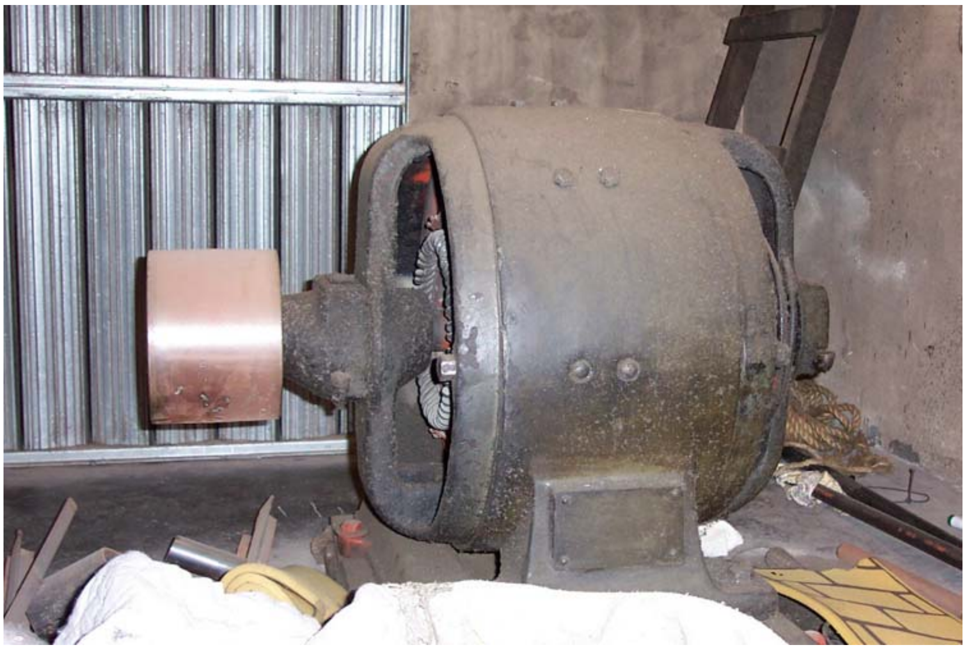

Fig 30 Original 25 HP DC motor for return air fan


Fig 31 Return air fan 60 HP 3 phase AC motor installed in 1992.

The main system originally incorporated two air washers using water sprays. These were located in the supply air stream just after the fans. The water was supplied by an artesian well, the well pressure being sufficient for operation of the spray heads. Spray water was collected in a reservoir and pumped to city sewer using a DC motor operated pump. (Figure 32) There was no water re-circulation. The air washer was used until 1988, at which time it was replaced with conventional filters. (An air washer was a device commonly used in plenum type heating systems in the 1890's – 1930's. The washer used water sprays to filter and humidify the air in winter. Since the washer typically used cool well water, it also provided some comfort cooling in summer, although humidity control was minimal.) When conditions warranted, additional cooling was provided by mechanical refrigeration from direct expansion pipe banks using carbon dioxide refrigerant. The pipe banks were located either in the air washer compartment, or right after it. (note: from 1952 until 1988 there was no mechanical refrigeration.) The only remains of the original air washers are the DC water pump and water well. From 1988 to 1992, mechanical refrigeration was provided in both main and balcony air streams using conventional finned coils in place of the air washers. The chilled water was supplied from a 120 HP Carrier package chiller. The chiller was taken offline in 1992, the chilled water then supplied from the downtown district system using the same fin coils.

Fig 32 DC motor driven pump for air washer

Mechanical system steam side

The original system used a combination of "hot blast" and direct radiation. The air system provided auditorium heating using extended surface pin type cast iron radiator banks in the air stream. (Figure 33) These were controlled in four stages by Johnson pneumatic thermostats located in the supply fan inlet plenums. (Figure 34) Supplemental heating was provided in the auditorium with indirect radiators, that is, concealed radiators in the floor, over which supply air flows through grilles at the auditorium door thresholds. Additional heating for backstage, lobby and various individual upstairs rooms used direct radiation, that is, individual radiators. (Figure 33 A) These were enclosed in the wall under fancy grilles, except in the backstage which used 3 wall mounted serpentine pipe coil banks, each about 20 x 20 feet. The live steam was originally supplied from combination gas and coal fired Kewanee boilers, which were removed in 1992. (The boilers normally operated on gas, but during peak heating times, the utility could mandate switching to coal.) In 1992 the theater hooked up to the downtown district steam system. The backstage radiators are gone, and the cast iron radiators in the balcony air system were removed in 2006. (Dave Marietta commented that these radiators were seldom used, all heating requirements being met by the main floor heating bank and the direct radiators.) Also, some of the dressing rooms in the front of the building had supply and return air ducts connected to the main plenums, but many of these were disconnected in 1992.

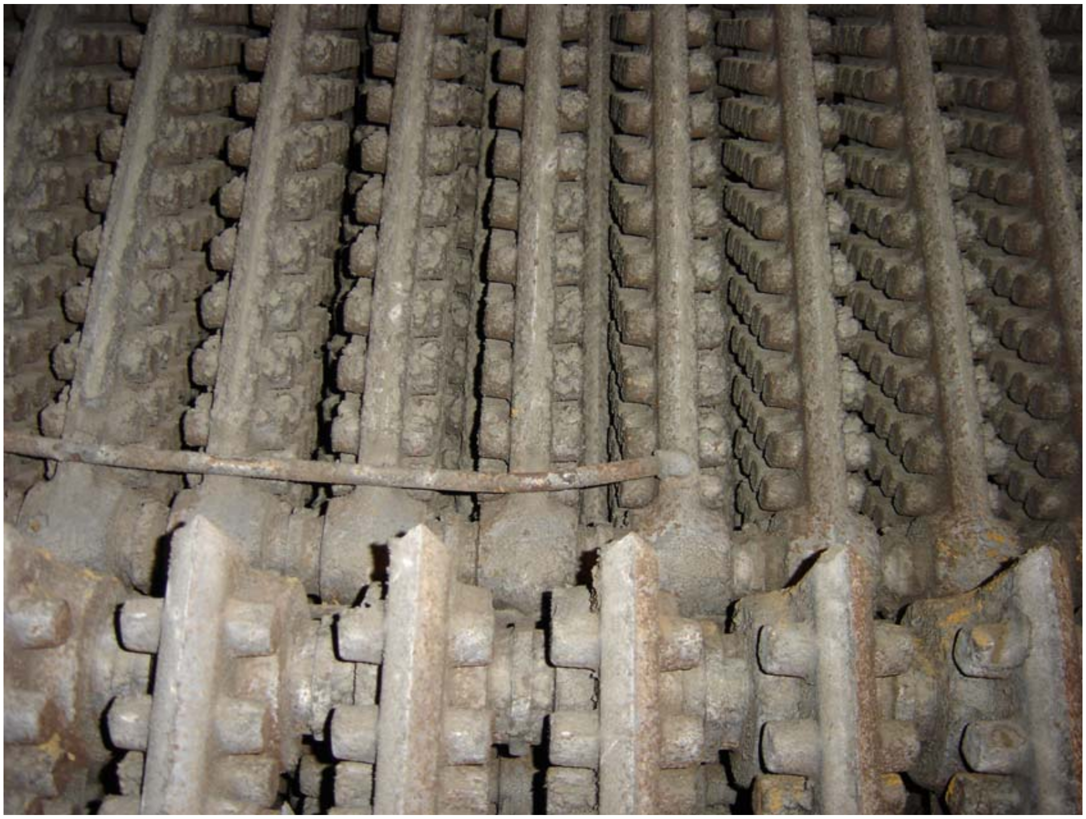

Fig 33 Cast iron heating surface at Orpheum Theater

Fig 33A Radiator grille in lobby.

Fig 34 Johnson 4 stage controls for main supply air.

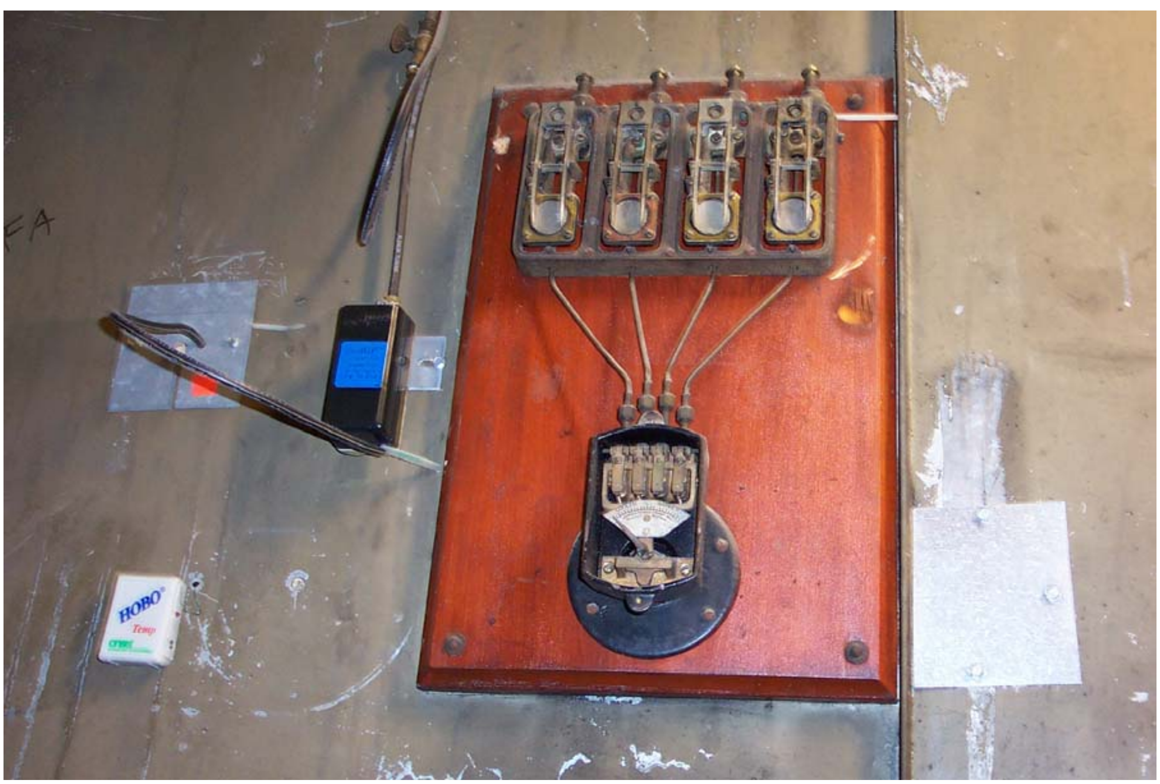

Fig 35 Original Johnson temperature control panel for balcony supply fan

Mechanical System Refrigeration

The original refrigeration system consisted of a Carbon Dioxide horizontal compressor operated by a 100 HP DC motor, connected by a flat leather belt. (Figure 36) The condenser was water cooled, tube in tube type. The evaporator was direct expansion bare pipe coils located in the main floor air washer compartment, the pipe coils bathed in the water spray.

The compressor has a flywheel of 120 inches. The compressor stroke appears to be about 20 inches. The compressor cylinder bore appears to be 8 inches. (Figures 37, 38, 39) The compressor, condenser and evaporator were manufactured by Wittenmeier Machinery Company, Chicago. (see Wittenmeier history below) Originally a gauge board was mounted on the wall with three pressure gauges, two for the low side pressure at each cylinder end, and one for the discharge pressure. These gauges are labeled in atmospheres, rather than PSI. The gauge board has been disconnected but still exists. (Figure 40) The evaporator and water cooled condenser no longer exist. The compressor exists but with some piping disconnected and missing.

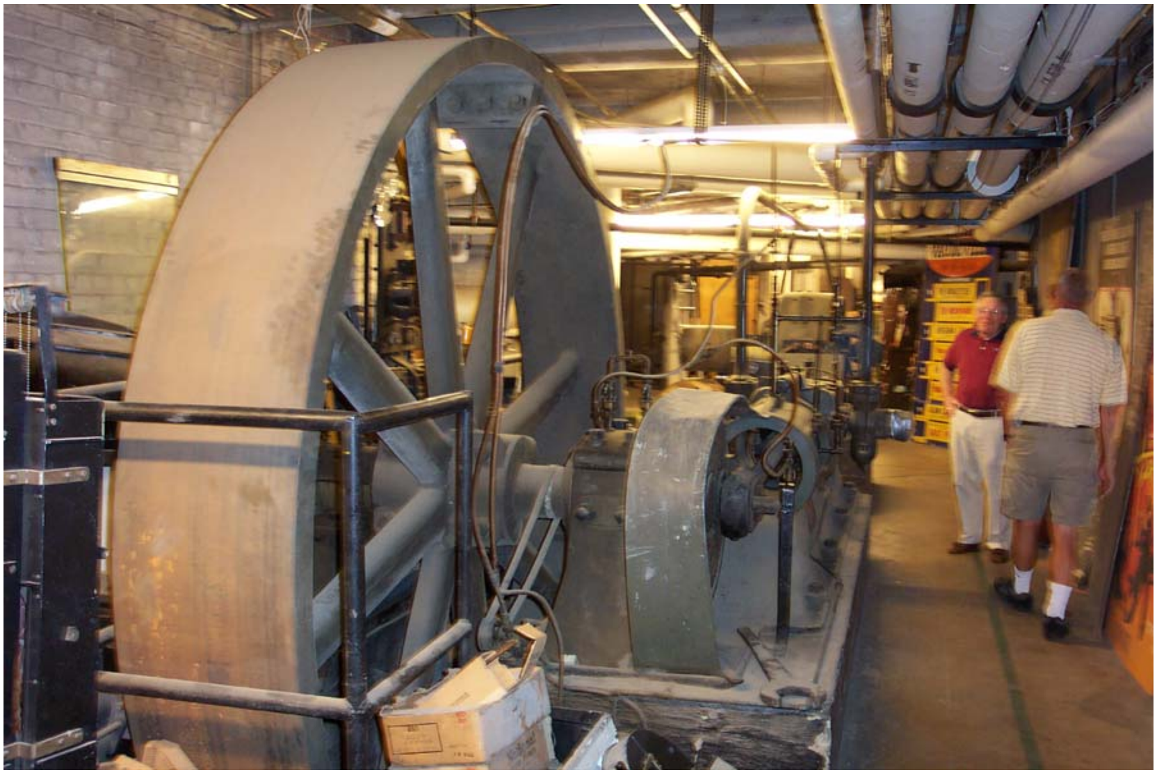

Fig 36 Carbon dioxide compressor, viewed from flywheel end.

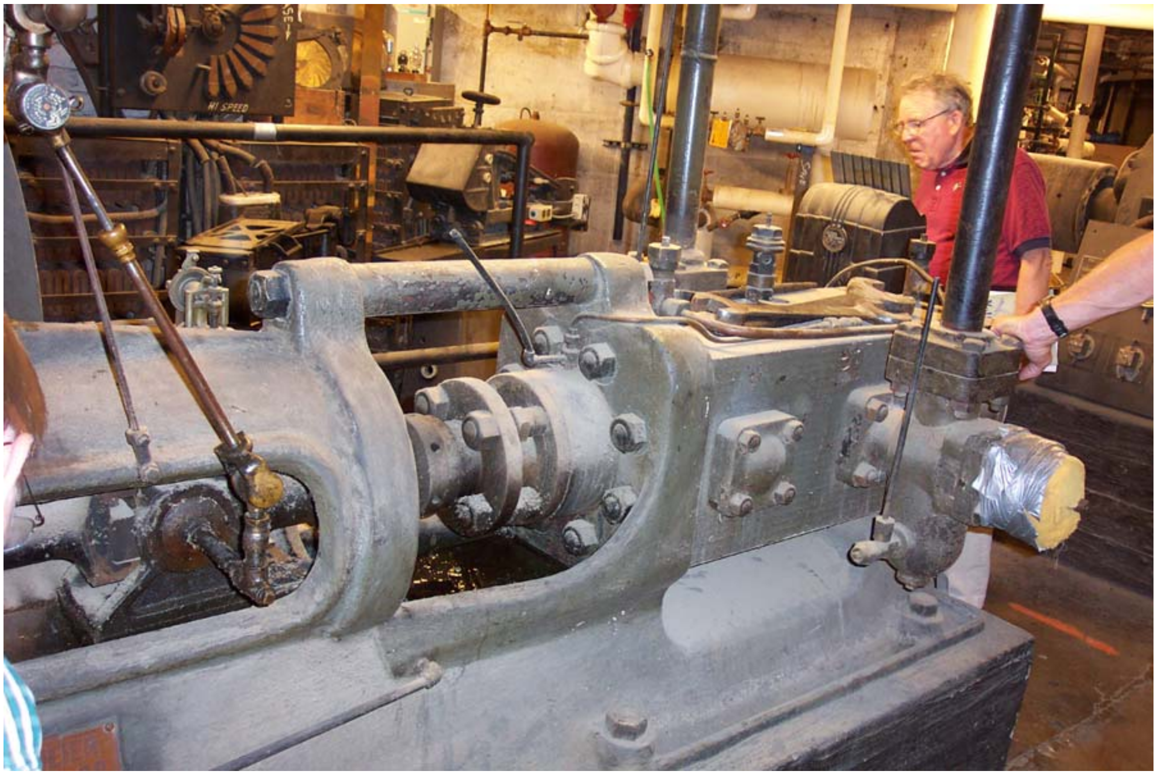

Fig 37 Carbon dioxide compressor, cylinder end.

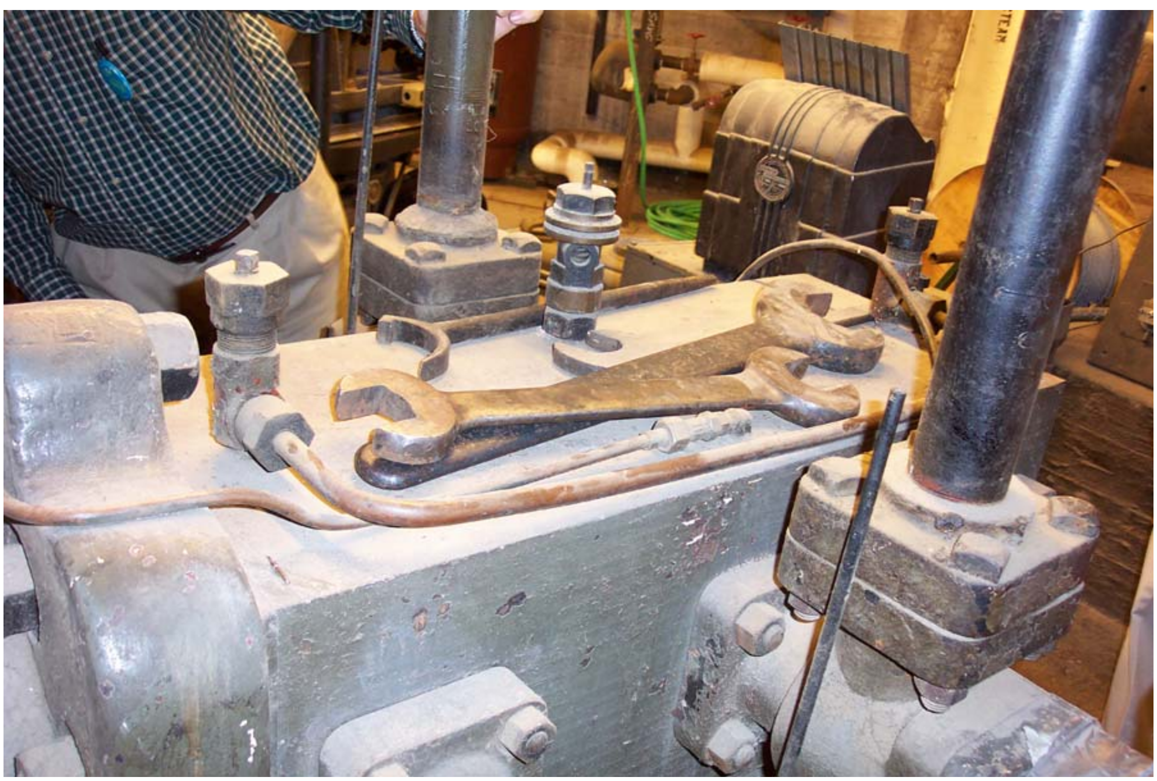
Fig 38 Close-up of compressor cylinder.

Fig 39 Flywheel bearing area showing oil pump for bearings.

Fig 40 Compressor gauge board.

The compressor motor is 100 HP, Direct Current, Compound type, 230 Volts, 750 RPM manufactured by the Sprague Electric Works of the General Electric Company. (Figures 41, 42) The motor incorporated an external “starting box” which used a rheostat (variable resistance) to bring the motor up to operating speed. (Figure 43) This was wired into the armature circuit of the motor. (DC motors must be started gradually to avoid excessive inrush current) The starting box also was used to control the speed of the motor if necessary. Both the motor and starting box are present at the theater site. There may have been two evaporators, one for each supply fan. Dave Marietta said there was an evaporator in the main supply fan air stream, but none for the balcony fan, however he assumes that there used to be one. In recent years Dave employed manual reheat using the main floor fan when cooling.

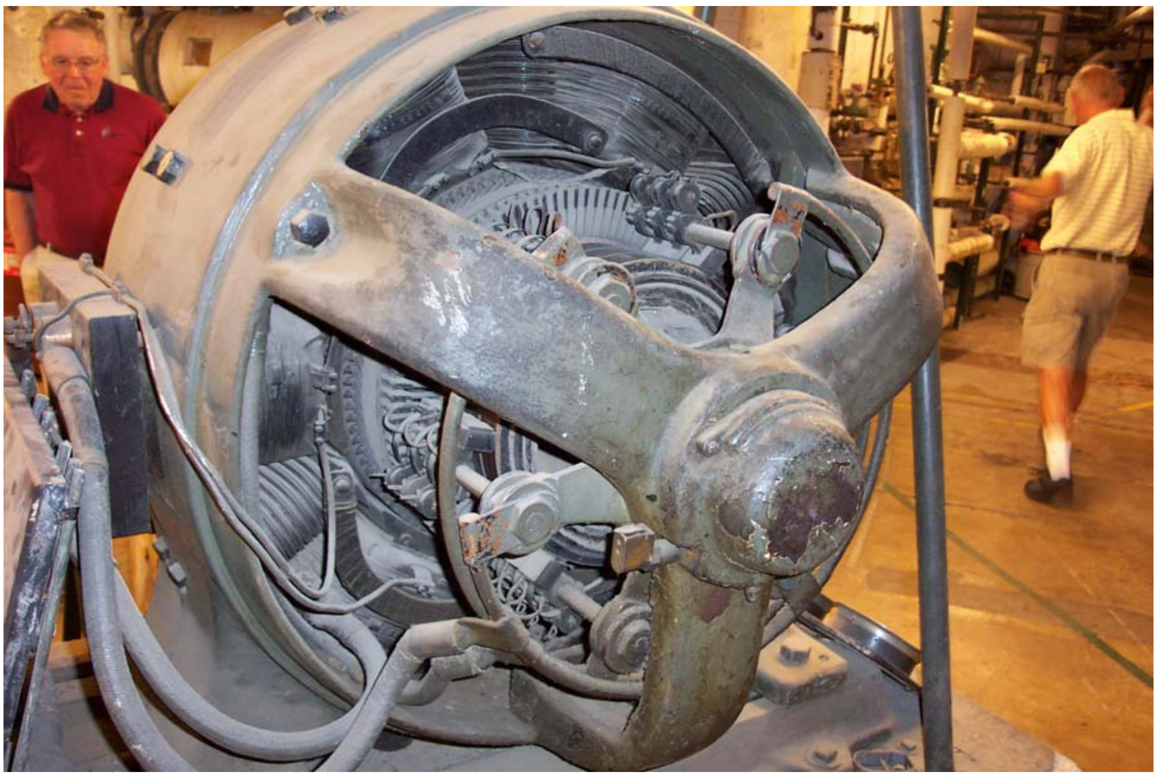

Fig 41 100 HP DC motor for compressor.

Fig 42 DC supply conduit and leads for compressor motor.

Fig 43 Starting box for compressor motor.

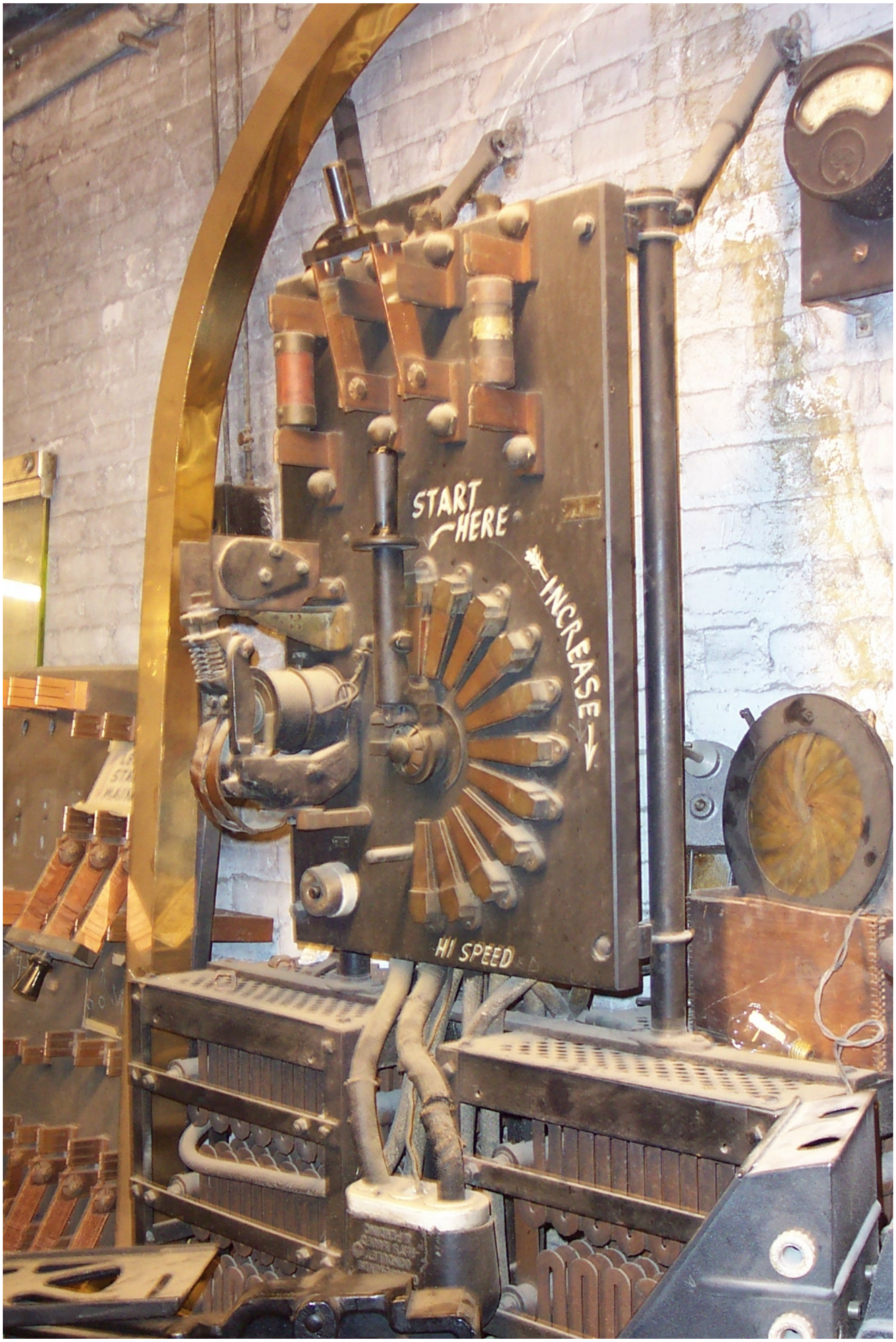

Fig 43 Starting box for compressor motor.

Original Control System

The original main heating system used Johnson pneumatic controls. (Figure 44) Individual rooms had radiator valves controlled by thermostats. The lobby radiators were also controlled this way. As previously mentioned, the heating surface in the supply air was controlled in four stages by Johnson thermostats in the air stream, activating the steam valves to each heating stage. Individual supply air ducts were modulated manually using adjustable doors inside the supply plenum. (Figure 45)

Apparently there was no automatic control for the cooling system. The refrigeration system was probably controlled manually, and the direct current motor driving the compressor could have been operated at reduced speed.

Most of the original controls were replaced by a new system in 1992.

Wittenmeier History

Fred Wittenmeier (1863 – 1928) began work with carbon dioxide refrigeration systems after he joined Kroeschell Brothers Co. in Chicago in1896. After 1900 he began to use refrigeration for comfort cooling, designing some of the earliest comfort cooling systems for theaters and hotels in the US. He later formed his own company, Wittenmeier Machinery Co. in 1917. The new company specialized in comfort cooling installations using forced air systems incorporating air washing and direct expansion refrigeration. Wittenmeier designed many of the cooling systems used in theaters in the 1920's.

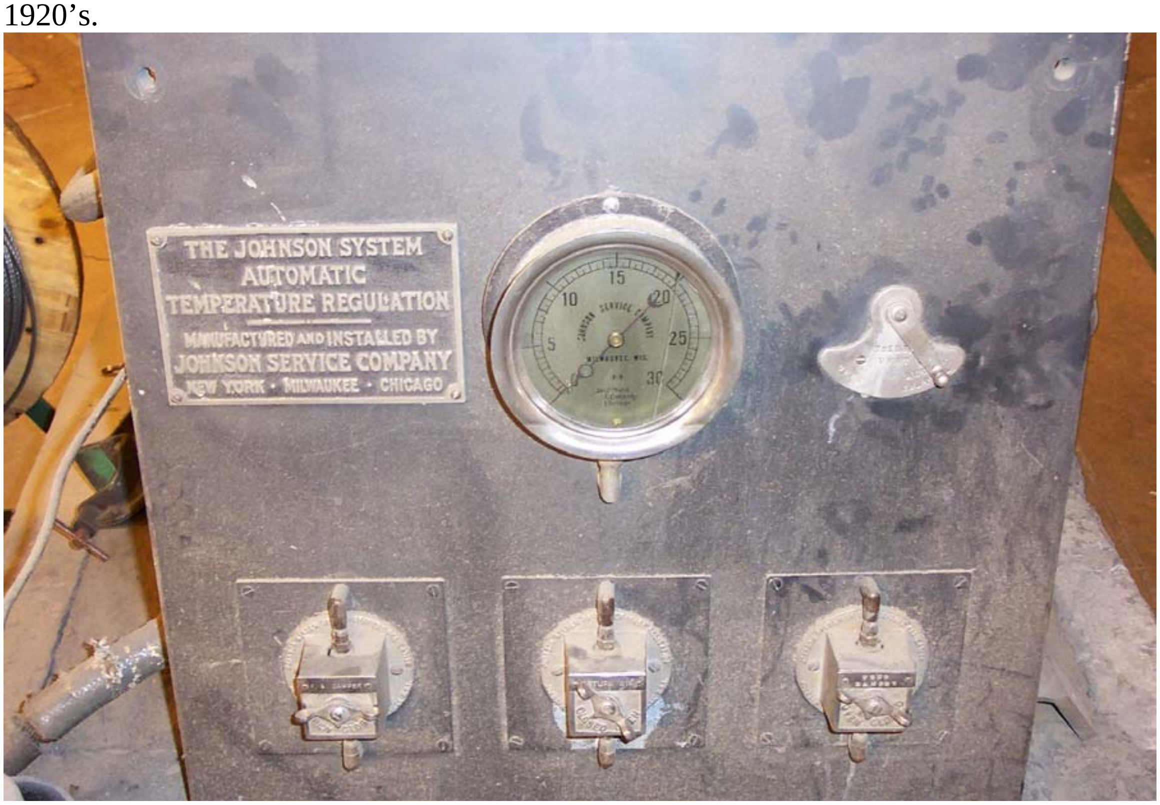

Fig 44 Original Johnson temperature control board.

Fig 45 Supply air damper with adjustable door latch for balancing air to individual supply ducts.