



## History of Air Rotation®

The concept of Air Rotation® was invented and patented by the Johnson Heater Corporation in the 1950's. The inventor was Nelson Johnson who began his investigation of this concept in the early 1940's. The early experiments were done with large floor furnaces designed for gravity heat distribution. Nelson modified the furnaces to provide a single point of introducing heat into a large open space, and then modified the furnace to circulate the heat output with a ductless fan system. The early systems took the form of a brick mason building a firebrick heat chamber and various forms of indirect-fired metal shell and tube air-to-air heat exchangers. The early experimental data indicated the key to properly conditioning a large open space was the air circulation between a high discharge and a floor level return. Heat could be directed, or ducted into a large building by any number of heat producing devices; but if it was not evenly distributed there would be hot and cold spots, stratification and wasted heating fuel that would fail to satisfy the thermostat control. Nelson gathered vast amounts of data and monitored the heating fuel used in actual buildings. To monitor fuel usage on a fair basis, he used the then newly developed "Degree Day Method", a system pioneered by fuel oil distributors to predict when fuel oil deliveries would be needed by their customers. Nelson was able to show considerable fuel savings while providing other demonstrable benefits. The patent on the Air Rotation® concept was merely the beginning. The application of the Air Rotation® concept has been constantly refined by Nelson's successors at Johnson Heater Corporation.

The early Air Rotation® systems in the 1950's and 1960's used a centrifugal blower to distribute the heat in the large open plan buildings. The early Air Rotation® units were free standing ductless floor mounted units and did not require the high static handling capability of centrifugal fans. Johnson Engineers developed quiet, high-efficiency axial fans that could adequately move the air through the heating unit and provide the necessary air circulation in the conditioned building. We were successful, and as an example, by the mid 1970's two horizontally mounted axial fans of 7-1/2 Hp. each were doing the job of a previous 40 Hp. centrifugal blower. This, however, was only the beginning!

Johnson Engineers have made many improvements in the Air Rotation® units with current models incorporating the best available technology. The hardware improvements are too numerous to mention in this write-up. However, the refinement of the Air Rotation System® is only part of the story. Where Johnson excels is in the application of this technology, a description of which follows.

### **Air Rotation® Concept**

The Air Rotation System® uses a high volume, low velocity, air-circulation system to distribute conditioned air to a large open space. We say "conditioned air" because the air in the space may be heated, cooled, humidified, dehumidified or supplemented with outside, fresh air as defined by the requirements of the space. While we initially describe the heating system (which was how the Air Rotation® concept began), it has been further

refined to include all the functions of a total conditioning system, including general ventilation. Other conditioning functions are described later in this write-up.

The general concept of Air Rotation<sup>®</sup> is to return all the air in the space to an Air Rotation<sup>®</sup> unit a sufficient number of times per hour to ensure an even distribution of the conditioned air. This concept provides for an even temperature distribution of the conditioned air product. Throughout the building, the temperature will not vary by more than  $\pm 2^{\circ}\text{F}$  from set point and more frequently will only vary by  $\pm 1^{\circ}\text{F}$ . Some variation is due to hysteresis of the temperature control. Additionally, the measured temperature variation throughout the building height will typically indicate a maximum 2-degree temperature rise for every 10 feet of elevation increase.

The Air Rotation<sup>®</sup> unit is designed to pull the return air to be conditioned into an Air Mover Module at floor level by means of a continuously circulating fan system. The Air Mover Module has a thermostat that measures return air temperature. When the thermostat detects the requirement to add building heat, for example, the heat module directly above the Air Mover Module will function to heat the air. The air-heating device may be an indirect-fired heat exchanger with a gas burner, steam coil, hot water coil, etc. The discharge air is passed on to an air outlet where it is directed into the space, typically near the ceiling. The heated air is a low temperature product, generally only  $20^{\circ}\text{F}$  above the thermostat set point. This low temperature air, when delivered to the space, will mix better with the existing ambient air and will not stratify as easily as if it were delivered at a high temperature.

Many other heat delivery systems use a high temperature rise to deliver air with a temperature 70 or 80 degrees or higher than the space temperature and with a volume (CFM) of less than one fourth of the capacity of the Air Rotation<sup>®</sup> system. Further, as soon as the thermostat is satisfied, the air delivery ceases. All of these factors encourage air stratification as the warmer (lighter), more buoyant air takes off for the ceiling.

Some of these heating systems can do a credible job in a low ceiling, or in an irregular shape building such as a "C" shape, whereby using positive pressure they can push the air toward leakage areas and obtain a pseudo distribution. However, as buildings become tighter and as building construction techniques have improved, there is less building leakage, and the effectiveness of these other systems is diminished; or conversely, as many doors are opened (as in the case in many warehouses, distribution and manufacturing buildings), the building's positive pressure will drop, and all conditioned air will exit the door openings with no real conditioning occurring in the quiescent areas of the building.

With other, competitive equipment, the majority of space thermostats are located five foot off the floor at the personnel working level. In response to the thermostat, the heat system runs to deliver a comfortable product to the personnel at floor level, all the while it is in essence heating from the top down because of the stratification effect. This top down heating wastes heating fuel. Some of these systems also use poor control systems to compound the problem. For example, four thermostats that are positioned in a large open space may be wired to temperature-average the space. If they are all set at 65 degrees and their readings are 60, 60, 70 and 70 you have a net average of 65; but the temperature difference will be 10 degrees between the highest and lowest readings.

The Air Rotation<sup>®</sup> system avoids the problems described for these other systems by its continuous circulation of a high volume low  $\Delta T$  heated air. The Air Rotation<sup>®</sup> system does not need a temperature-averaging system described above, as it is bringing the building air back to the Air Rotation<sup>®</sup> unit. It is a physical averaging system by the fact it brings all of the air in the building to the unit several cycles every hour. The Air Rotation<sup>®</sup> heat source runs when the return air thermostat senses the temperature drop below set point. In a manufacturing operation with heat gain, the Air Rotation<sup>®</sup> unit will capture the heat gain and disrupt stratification, thus using less heating fuel. Other methods of heating without continuous air circulation don't have the ability to capture any heat gain from the conditioned space. Examples of heat gain sources include machinery, people and the lighting load. Everyone is aware that warm air rises and the area under the roof has the greatest heat loss in any building. Warm air will only rise and stratify when there is no impetus to cause it to circulate to a lower level. When there is no fan to effect air movement, air will immediately begin to stratify according to temperature and the laws of physics. Think of the warm air discharged at ceiling level from the Air Rotation<sup>®</sup> unit as having a slightly positive pressure with respect to the floor level, while the air in the lower portion of the building is slightly at a negative pressure with respect to the upper level as it is being pulled toward the Air Rotation<sup>®</sup> unit. If you pull the rug out from under the upper level air it has to come down. This is the entire principle of Air Rotation<sup>®</sup>. We use many schemes of fan utilization including Variable Frequency Drives to optimize the Air Rotation<sup>®</sup> system. The trade-off between fan electrical consumption vs. fuel savings is always favorable to the end user; but the bottom line is, "No Fan – No Rotation" and no fuel (energy) savings.

Our Air Rotation<sup>®</sup> units are generally designed to throw, or project air up to 400 feet from the heat source. We provide our units with a custom-designed air outlet for each space that can directionally project the conditioned air out over the tops of storage racks, etc., where it gently drops down into rack aisles and these aisles then become our invisible return air ducts. For this reason it is necessary to have a certain minimum height for the Air Rotation<sup>®</sup> principle to work properly. If the building is less than 12 feet in height or has a poor height to width and length ratio, the Air Rotation<sup>®</sup> unit cannot physically be built high enough to project the air away from the unit and it will "short cycle" and not condition the building properly. The Air Rotation<sup>®</sup> concept is the best choice for a high ceiling, large cubic content building.

The heat loss on any building is calculated by all of the standard accepted formulae. However, we can look at the building envelope in a different way.

As an example, assume a building is 400 ft. x 500 ft. with a 40 ft. high ceiling. Also, assume this building is heated with a plethora of suspended unit heaters and various thermostats located at 5 ft. elevation and a 65°F set point. Satisfying the thermostat(s), the building will have 65°F average temperature band around the inside periphery of the building in the first 10 ft., the next increment from 10 to 20 ft. might be 75°F, the next increment from 20 Ft. to 30 Ft. might be 85°F, the next increment from 30 to 40 Ft. could be 95°F, while a final "under-roof" temperature could be as high as 100°F. The owner probably doesn't realize this temperature difference because he walks around his building on the floor and not on the ceiling. However, ask any maintenance man who has had to perform work near the ceiling in the middle of winter and he will confirm this higher temperature. Admittedly this is a graphic example; but we have measured many buildings with stratification to a greater extreme. Assume also this building has a wall value of R8 ( $U=0.125$ ) and a roof value of R11 ( $U=0.09$ ). We are neglecting infiltration and door openings for the purpose of this example, as we are about to demonstrate the

skin loss effect in an Air Rotation<sup>®</sup> heated building vs. suspended unit heater application. The inside design is 65°F and 0°F outside design, giving a ΔT of 65°F. The heat input needed to satisfy the 65°F thermostat set point at floor level should be calculated as follows:

UNIT HEATERS:

400 x	10 x	2 x	65 x	0.125 =	65,000
500 x	10 x	2 x	65 x	0.125 =	81,250
400 x	10 x	2 x	75 x	0.125 =	75,000
500 x	10 x	2 x	75 x	0.125 =	93,750
400 x	10 x	2 x	85 x	0.125 =	85,000
500 x	10 x	2 x	85 x	0.125 =	106,250
400 x	10 x	2 x	95 x	0.125 =	95,000
500 x	10 x	2 x	95 x	0.125 =	118,750
400 x	500 x		100 x	0.09 =	<u>1,800,000</u>
Total Btu/h Output Required					2,520,000

$$2,520,000/0.75 \text{ (Typical Unit Heater Efficiency)} = 3,360,000 \text{ Btu/h Input Required}$$

This is the correct way to calculate the heat input required for a stratified building. If calculated the conventional way to a 65°F ΔT throughout, the heating system will still use the fuel it needs to offset the building heat loss and the only time the owner notices this problem is when the building cannot be held to inside design temperature, when it is zero outside (unless excess capacity was originally included).

This same building when heated with an Air Rotation<sup>®</sup> system would be calculated as shown below:

AIR ROTATION<sup>®</sup>:

400 x	10 x	2 x	65 x	0.125 =	65,000
500 x	10 x	2 x	65 x	0.125 =	81,250
400 x	10 x	2 x	67 x	0.125 =	67,000
500 x	10 x	2 x	67 x	0.125 =	83,750
400 x	10 x	2 x	69 x	0.125 =	69,000
500 x	10 x	2 x	69 x	0.125 =	86,250
400 x	10 x	2 x	71 x	0.125 =	71,000
500 x	10 x	2 x	71 x	0.125 =	88,750
400 x	500 x		72 x	0.09 =	<u>1,296,000</u>
Total Btu/h Output Required					1,908,000

$$1,908,000/0.82 \text{ (Typical AR Heater Efficiency)} = 2,326,829 \text{ Btu/h Input Required}$$

Thus the difference between a Unit Heater building and an Air Rotation<sup>®</sup> building is calculated as:

$$(2,326,829/3,360,000) \times 100 = 69.2\%, \text{ hence the probable fuel saving is } 30\%.$$

If this were a manufacturing operation with heat to be recovered, or other dynamic building heat loss factors are considered, the fuel savings would be greater.

Air Rotation<sup>®</sup> heat utilization can be compared in any existing building by measuring stratified heat loss in 10 Ft. increments and applying the heat source efficiency to compare the difference.

## **Air Rotation® Cooling**

When Johnson Air Rotation® systems investigated air conditioning we found the same air mixing principles held true, that is, the delivery of cooled air, high into the conditioned space, with a low  $\Delta T$  provide the same even temperature distribution, low stratification numbers and lowered energy consumption. There is an ideal number of air turns for a “heat only” or “cooling only” space and another number of air turns for a combination heating and cooling application.

Johnson has discovered this information while performing design application engineering in billions of square feet of building space for the past 50 years.

Johnson Air Rotation® systems still uses an axial propeller fan, albeit of special design, to handle the higher static pressure over the filters and cooling coils when operating in cooling mode. Due to the density of the colder air, we de-rate the throw, to 250 or fewer feet for air conditioning. Nonetheless, the fan horsepower per ton in the ductless Air Rotation® system is significantly lower than any ducted or packaged system, frequently on the order of one fourth or less of the air moving horsepower of other systems. The Air Rotation® unit is most often located within the space to be conditioned, therefore, no additional factor need be added for return air duct infiltration from the roof. In the real world, the return air duct to the fan section of the case will not be perfectly sealed, hence additional heat gain must be added to the load calculation. Usually this is a factor built in to the manufacturer’s selection program. Most of the units are a constant volume air handler with either DX or CW cooling coils. All of the air in the conditioned space is passed over the cooling coil(s) several times per hour, resulting in humidity control anywhere in the space to within a few percentage points.

Johnson provides both “blow through” and “draw through” designs; but generally the preferred design is the draw through unit, primarily for its even air flow across the coils and the ability to handle condensate removal at floor level. Additionally, all of the cooling coils, filters, etc. being at floor level are easily serviced, and the units are more easily maintained. “If it is easy to get to, it will probably be serviced”. The “easy-to-service” philosophy assists the owner in properly maintaining the equipment and assures the original operating savings projections for the life span of the equipment.

## **Make-up Air**

In order to meet various building codes and ASHRAE requirements, a specified quantity of fresh make-up air is often required. If the quantity of make-up air is not large in relation to the Air Rotation® circulating capacity, it may be put through the Air Rotation® unit, either by a wall vent on the return air side of the unit, or through a separate powered roof-top (or wall) fan with ducted air to be mixed and tempered in the outlet. Usually cooling applications take their make-up air at floor level and heating applications receive the make-up into the unit in either the high or low position. If the quantity of required make-up air is high in relation to the number of occupants, or building square footage, then a direct-fired make-up air heater (with cooling coil if required) may be an option, either by itself or with an Air Rotation® System to provide even temperature distribution throughout the space. For example, if you had a 60,000 Sq. Ft. building and your code requirement was for 0.1 CFM per Sq. Ft. then you would only need 6,000 CFM, well

within the capacity of an Air Rotation® System to provide this requirement. However, add a paint operation that runs 4 hours day with a 30,000 CFM exhaust requirement and you have a different situation. We would recommend a 30,000 CFM direct-fired make-up air handler, electrically interlocked with the paint operation exhaust fan, to run when the paint exhaust fan was running.

### **Ventilation**

The Air Rotation® units are not merely a heat circulating device. Even a “heat only” Air Rotation® unit can be used to participate in a year round ventilation plan. With the burner turned off, the Air Rotation® fan(s) may be used to circulate a large volume of low velocity air inside the building, thus reducing the quantity of actual wall supply fans by one-half or more. The Air Rotation® unit can also participate in many of the ASHRAE published summer night-time ventilation schematics, whereby the building is ventilated extensively over night and then closed up the next morning and the building is kept cool by the Air Rotation® unit’s air circulation until well into the afternoon, at which time the building heat gain will finally overcome the indoor temperature. Depending upon a number of building and climate factors, this ventilation scheme can average a temperature halfway between the nighttime and daytime temperature extremes.

Heating only units can have an optional condensation control included. This control can provide a measure of dew point protection to value added products damaged by condensation. Many steel storage facilities, where it is impractical to provide A/C, find this to be an affordable solution to a serious business problem.

### **Application Philosophy**

This brief write-up provides an overview of the Air Rotation® concept. The Air Rotation® concept can effectively be used in more applications than generally recognized. If you take away one thing after reading this brief description, the Air Rotation® system is a total building conditioning system. If you study the ASHRAE literature of the last fifty years on space conditioning it is always directed at getting the first 6-foot elevation in the space to a comfort level for people. Much of the literature, while very good (we use a lot of it) is directed at air throw from ducted registers and induced mixing, etc. However your situation may be one of the many that require a more energy-efficient, total conditioning system. Some examples would be a candy manufacturer that stores finished goods in a high-rise rack system 30+ feet off the floor and can’t have his chocolate melt in the summer; or a pharmaceutical manufacturer who, per FDA regulations, must control the temperature/humidity of stored drugs throughout a warehouse facility to a specified tolerance of a few degrees; or a plastics manufacturer with large amounts of process heat gain; or a printer with crucial temperature and humidity tolerances.

We have touched the surface on Air Rotation® and given you an overview of the rules we use to implement the concept. As always, there are situations we might do things differently than we have described. For example, we make a reverse flow Air Rotation® unit when the situation dictates. Every situation is different, and we ensure the Air Rotation® concept is not misapplied. If your application dictates another form of conditioning, we will be the first to acknowledge this fact.

Johnson will provide a system with the type of HVAC tool most appropriate for the specified task. As good as the Air Rotation® system is, occasionally there are other HVAC tools that we manufacture that are more appropriate for a certain task. We team

with others, such as condenser manufacturers, and mechanical contractors to provide the correct system design and ensure properly installed equipment to fulfill the customer's need.