

# Induction Beams

**Engineered Comfort for Today's Buildings**



turn to the experts<sup>SM</sup> 

**Carrier Corporation  
Syracuse, New York**

**May 2013**

## TABLE OF CONTENTS

INTRODUCTION .....	2	EQUIPMENT SELECTION AND LAYOUT.....	6, 7
ORIGIN OF INDUCTION TERMINALS .....	2, 3	DESIGN CONSIDERATIONS .....	7, 8
INDUCTION BEAMS: THE INDUCTION SYSTEM UPDATED FOR TODAY'S BUILDINGS .....	3, 4	Comfort and IAQ (Indoor Air Quality) .....	7
BENEFITS OF INDUCTION BEAM SYSTEMS .....	4-6	Acoustics .....	8
Efficient Room Air Mixing .....	4	Mechanical Room and Distribution.....	8
Primary Air-Powered Induction Effect.....	4	Controls .....	8
Outdoor Air Used as Primary Air .....	5	SUMMARY .....	8, 9
Conditioning of the Primary Air .....	5		
Latent Cooling within the Zone .....	5		
Smaller Distribution Systems .....	6		

## INTRODUCTION

Choosing the right HVAC system is a complex process involving many decisions. There are usually many good solutions, but providing a great system often starts with selecting the right terminal products to condition the occupied zones of the building. When the right terminals are properly matched with good central equipment to provide heating, cooling and ventilating, along with efficient air and water distribution out to the zones, occupants and owners alike are rewarded with superior comfort and lower energy usage intensity. A well-engineered system leads to engineered comfort.

This white paper presents the induction beam, an induction terminal that has been updated for today's buildings and applied in the ceiling plane. As we explore the induction beam (IB) system, we will compare it to the traditional variable air volume (VAV) system as well as another newcomer to the American market, the European-style chilled beam (CB) system.

## ORIGIN OF INDUCTION TERMINALS

When "skyscrapers" began to appear in our cityscapes, a new HVAC system was needed. Building taller allowed large total areas to be created without the expansive floor plans and associated high cost of center-city real estate. HVAC systems to that point had constant volume airflow with large central duct risers and extensive branching to the many diffusers. Zoning reheat coils required just as much piping and were energy inefficient. Willis Carrier invented the perimeter induction terminal to overcome these issues.

Compared to those in existing HVAC systems, duct risers in perimeter induction terminals were smaller, higher pressure, and located all along the building's perimeter. Zoning coils inside of furniture casework filled the space between the supply air risers. (See Figure 1.) The true innovation of this new system was the use of high velocity jet nozzles to distribute the conditioned air within the casework such that the low-pressure zone created by the jet velocity "induced" the room air across the coils for conditioning and mixing with the primary air, hence the name induction terminal.

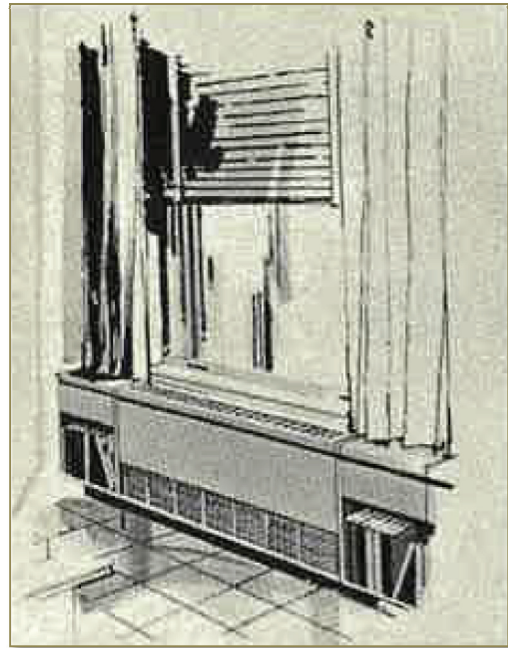


Figure 1 – Early Perimeter Induction Terminal Installation

Another departure from other systems of the time involved supplying 100% outdoor air to the induction nozzles, providing constant ventilation and superior indoor air quality to the occupied spaces. Control valves or dampers on the terminal modulated in response to changing zone loads to maintain the thermostat set point. This outdoor air, called primary air, was also sufficiently dehumidified to handle any zone latent loads as well, though drain pans were provided as a safety measure since buildings of that era were not without infiltration. (See Figure 2.) Since this primary air was the only air being circulated by the central air handler, both the air handler and the associated ductwork were much smaller than in the competing constant volume systems, which had to handle both outdoor air and recirculated room air at the central equipment.

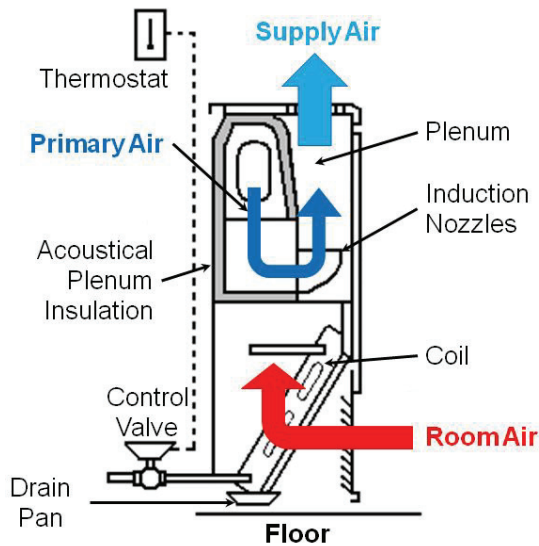


Figure 2 – Perimeter Induction Terminal Cross-Section

The perimeter induction terminal system was the system of choice for 1930's to 1970's mid-town high-rise office towers. As the building stock moved away from the skyscraper profile, certain negative aspects of the perimeter wall induction terminal became more significant. Excessive fan energy associated with the high pressure primary air requirements of the nozzles (up to 2 in. wg) and rezoning difficulties did not meet the needs of new building occupancy profiles. The perimeter induction terminal system became a system of the past and was replaced by the traditional VAV system.

### INDUCTION BEAMS: THE INDUCTION SYSTEM UPDATED FOR TODAY'S BUILDINGS

Any good system requires continuous improvement and attention to detail in order to maintain viability. The changes that have brought induction terminals once again to the forefront of HVAC systems are: 1) Improvements in nozzle design that lowered both generated sound (NC 30 max) and required inlet pressure (reductions of up to 80%); 2) the ability to handle both sensible and latent loads at the zone (see Figure 3); and 3) the use of energy recovery ventilator dedicated outdoor air systems to supply the primary air without the major preconditioning penalties of old-style systems. The modern induction system offers significantly lower energy usage intensities (EUI), with kBtu/sq ft values as low as the best systems commonly used today in commercial buildings. With HVAC loads dropping in many areas (i.e., tighter exterior envelope and

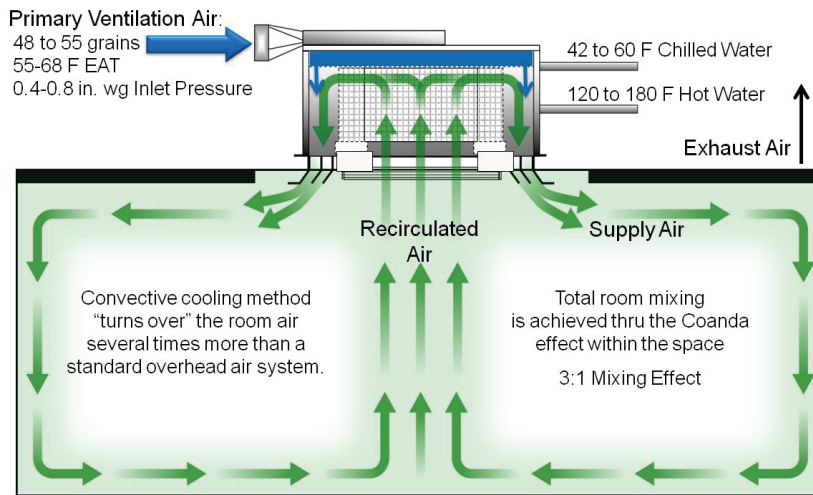


Figure 3 – Induction Beam Airflows

more efficient lighting), the total conditioned air being delivered to the zone to meet cooling and heating loads has dropped, making the benefit of the induction terminal's continuous outdoor air ventilation more and more important. Induction beams include drain pans that offer the additional benefit of latent cooling at the terminal. Chilled beams provide the same induction effect as induction beams but traditionally are designed to handle the room sensible load only and do not have drain pans.

The next section further describes the benefits of the induction beam, in particular the Carrier all-way-blow style as compared to the traditional VAV system and the chilled beam system.

## BENEFITS OF INDUCTION BEAM SYSTEMS

### Efficient Room Air Mixing

All three systems (IB, CB, and VAV) provide room comfort by introducing conditioned air and mixing it with the air already in the space. The supply air has been heated or cooled, dehumidified, and filtered to meet the environmental conditions for occupant comfort set for the project. A mixing system, as opposed to a displacement or radiant system, seeks to achieve an overall uniform set of environmental conditions within the space, most notably dry bulb temperature and air motion. Both types of induction terminals (IB and CB) are successful in this effort

because of their high induction ratio of room air to primary air. Variable air volume terminals rely on proper selection and layout of high-induction style linear diffusers for good mixing, otherwise they will likely experience loss of the Coanda effect at low loads and the supply jet will drop into the occupied zone of the space, likely causing high velocity air motion discomfort. Chilled beam terminals do not have the low load issue, but with the higher number of terminals required to satisfy peak loads there is a concern that opposing airstreams may collide with each other and drop into the occupied zone. The low velocity of the air in the occupied zone conditioned by an IB terminal eliminates drafts in the space providing the best overall evenness of temperature and air motion velocity, resulting in superior occupant comfort satisfaction. (See Figure 4.)

### Primary Air-Powered Induction Effect

Through the use of high-velocity jet nozzles and the resulting induction of room air into the primary airflow, induction terminals need no electrically powered fans to provide the supply air volumes required to condition the zone. Induction beam terminals require significantly less primary air inlet static pressure than their induction terminal predecessors, generally between 0.4 and 0.8 in. wg. Variable air volume terminals using appropriate linear diffusers exhibit the desired induction effect, but the use of multiple cfm-limited diffusers increases the risk of high-air motion discomfort in the occupied space.

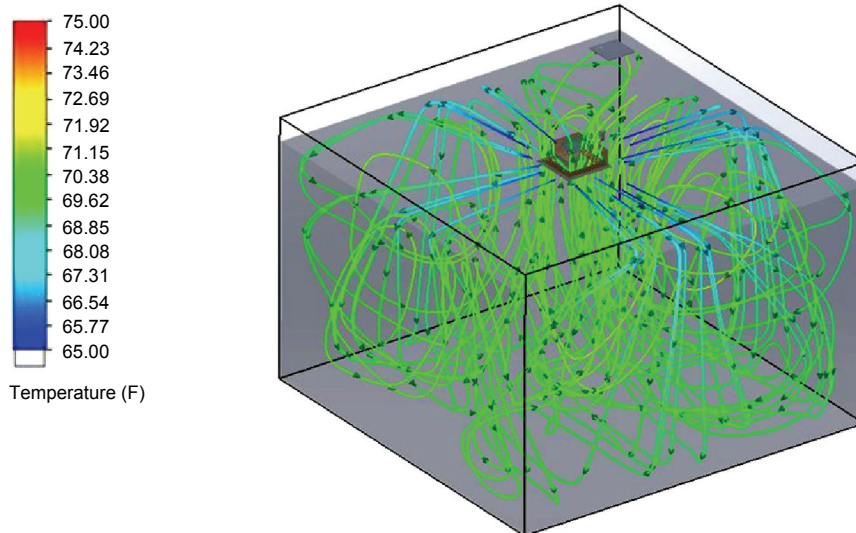


Figure 4 – Room Air Mixing Effect of IB Terminals - Temperature

Use of IB or CB terminals in the zone reduces the AHU (air-handling unit) size in comparison with a VAV system, which reduces the system fan power required, saving energy. In the early stages of the product development, an independent study was commissioned to compare four HVAC system choices for a K-12 school in the Southern Tier of New York State. The study was conducted by CDH Energy using the DOE-2 modeling program, and as seen in Table 1 below, the IB solution was nearly as good as geothermal heat pumps and a full 20% lower in energy cost than the VAV choice. Over the last decade, similar studies continue to show such favorable comparative results.

A good practice to follow when starting a new project is to develop a full building energy model using Carrier’s HAP (Hourly Analysis Program) system design and energy analysis program, (or other analysis programs such as Energy Plus or eQuest) and then evaluate the energy priority compliance of each system using project-specific characteristics.

### Outdoor Air Used as Primary Air

A major feature of an induction system is its use of 100% outdoor air (OA) to drive the nozzle jet induction effect. This means that whenever there is air flowing through the terminal, approximately 1/4 to 1/3 of the airflow is outdoor air, providing ventilation of the space at or above code minimum requirements. The ventilation air to the space is always measurable and consistent, whereas it is not possible to directly measure the ventilation airflow to the space in a VAV system. It has been said that CB terminals over ventilate the space because primary airflow greater than the ventilation requirement is often needed to handle the space load that cannot be fully met by the coil in the beam. The high-capacity coils in Carrier’s IB terminals do not require increase of the primary airflow to meet

room loads. In fact, most IB designs set the code outdoor air minimum values as the primary air design point, providing the superior IAQ made possible by this continuous dilution ventilation.

### Conditioning of the Primary Air

Using the central air handler to condition the primary air offers many advantages. The outdoor air can be highly filtered to remove particulate matter and obnoxious or harmful gases [VOCs (volatile organic compounds) and SVOCs (semi-volatile organic compounds), compounds like formaldehyde, and oxides of nitrogen and sulfur]. Variable air volume systems can likewise provide this efficient means of cleaning the outdoor air, though the delivery rate of the ventilation air changes as the units respond to changes in the zone loads.

### Latent Cooling within the Zone

The Carrier IB terminal is explicitly designed to provide latent cooling of the induced room air. The moisture removal load created by people is equal to or greater than the sensible load they produce, so this alone creates an incentive to handle latent cooling at the zone level.

The means for providing this capability with CB terminals is to dry out the primary air well below the room dew point, then “absorb” the excess moisture when the supply air mixes within the room. If the building envelope is deemed moisture-tight and there are few internal latent loads, then the CB terminals can lower the primary air temperature sufficient to dry it out and provide the latent cooling. VAV solutions also employ this principal, but with no direct control over the ventilation airflow, room relative humidity varies more than with an IB which can more directly control room relative humidity.

**Table 1 – CDH Energy Study – Cost Comparison of HVAC Systems for K-12 School**

DESIGN FACTOR	VARIABLE AIR VOLUME			4-PIPE FAN COIL			INDUCTION BEAM			GEOTHERMAL HEAT PUMP	
	Electricity (mWh)	Gas (therms)	Cost (\$)	Electricity (mWh)	Gas (therms)	Cost (\$)	Electricity (mWh)	Gas (therms)	Cost (\$)	Electricity (mWh)	Cost (\$)
Lights and Equipment	306		37,089	306		37,089	306		37,089	306	37,089
Space Heating	21	18,971	17,728	21	18,789	17,515	15	9,728	9,659	43	5,209
Space Cooling	68		8,260	46		5,564	71		8,626	57	6,901
Pumps	29		3,520	28		3,385	21		2,576	7	802
Fans	46		5,521	39		4,751	12		1,501	62	7,522
<b>Totals</b>	<b>470</b>	<b>18,971</b>	<b>72,118</b>	<b>440</b>	<b>18,789</b>	<b>68,304</b>	<b>426</b>	<b>9,728</b>	<b>59,451</b>	<b>475</b>	<b>57,523</b>

Also, with most VAV systems, the central air handler does not dry out the supply air as much, so the terminals are even less able to control room moisture levels.

When first developed, the induction terminal used the dehumidified primary air method, but now the Carrier IB terminal brings to the market an induction terminal with an integral drain pan to catch cooling coil condensate and discharge it into the condensate piping system. If the IB terminals are provided with very dry primary air, the drain pans do not need to be piped for condensate removal and they become a secondary safety measure to prevent moisture-staining. A moisture sensor or float switch can be provided to warn if condensate begins to accumulate in the pan. The integrated drain pan on the IB terminal also allows use of chilled water temperatures down to 42 F, providing additional coil capacity, including latent. Chilled beam terminals are sensible-only cooling devices requiring that the chilled water be provided above the dew point temperature of the space, generally at 58 to 60 F. Condensate or moisture sensors are commonly used on CB terminals to shut off the chilled water flow when the temperature of the chilled water supply is below the room dew point.

### **Smaller Distribution Systems**

If first cost is a concern, real savings exist in many areas when using an induction system. Since the central system is only conditioning and distributing the much smaller volume ventilation air (compared to the total supply airflow in a VAV solution), duct mains will be smaller, and with fewer, larger IB terminals employed, then branch ducting becomes much less extensive.

Since drain pans are standard on IB terminals, the primary air delivery temperature can be even lower still, increasing delivered capacity per cfm. If the primary airflow using neutral delivery temperatures exceeds the ventilation air requirement, then the colder primary airflows would further reduce the size of the ductwork. The same argument applies for the chilled water distributed to the zone terminals for cooling of the induced air; with higher delta temperatures the pipe sizes get smaller. Both of these reductions in distribution requirements save money for material and labor.

With no fans in the terminals there is no power wiring out to the zones, only control wiring, and again, more cost savings. With simple two-position water valves and primary air inlet dampers, IB

terminals are the simplest to install, operate and maintain on the controls side as well. The condensate piping system for the IB terminal system or the moisture sensors for CB terminals would add an additional cost, but much less than what has been saved so far. VAV solutions enjoy the same “no power wiring” advantage, but only limited duct size reduction, and duct size will be reduced only if true load diversity exists in the chosen layout.

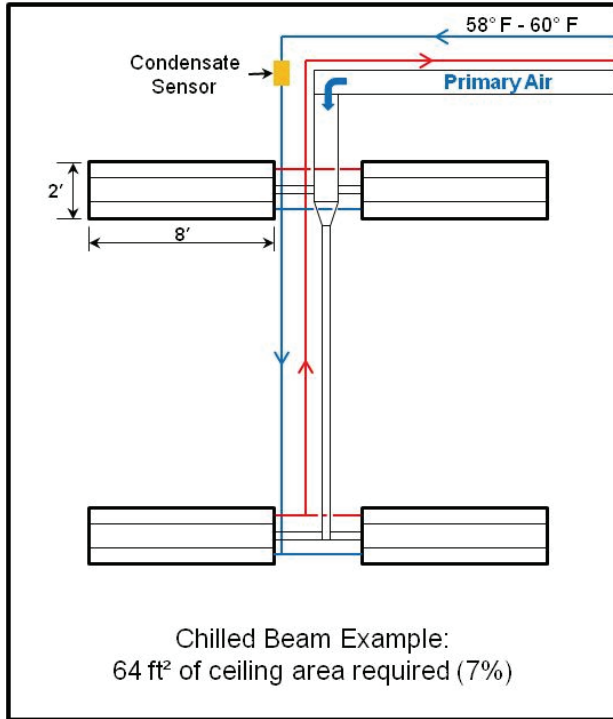
### **EQUIPMENT SELECTION AND LAYOUT**

Like any system solution, terminal equipment can be selected and laid out preliminarily at early stages of design, soon after initial HVAC loads have been calculated. Using tabulated performance data and working with knowledge of the floor plan and available space above the dropped ceiling, one can study sizes and numbers of terminals to see what coordinates best with the room architectural features and planned lighting design. To more fully realize the installed cost advantages of the Carrier induction beams, the layout should make use of fewer numbers of higher capacity terminals, keeping ductwork and piping costs lower than if larger numbers of low and medium capacity units were chosen.

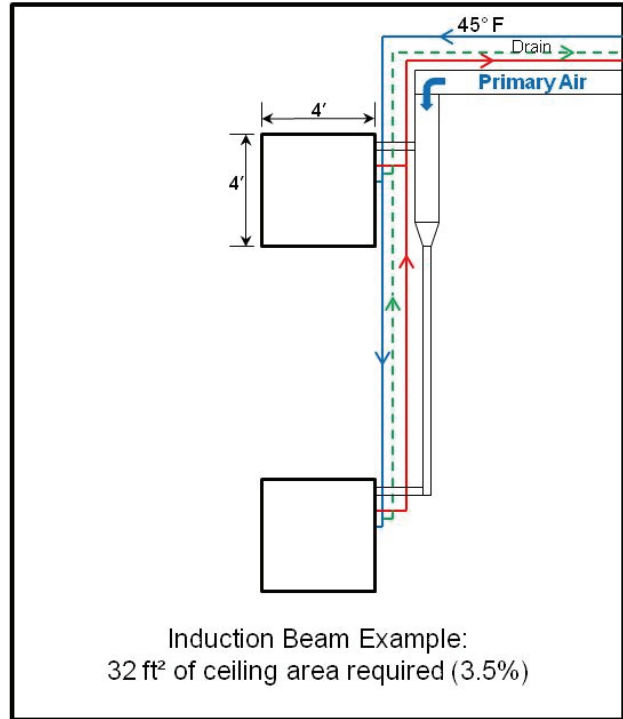
Remember, the colder the entering water temperature, the greater the coil capacity; however, this will also decrease chiller efficiency. While the goal is to select the minimum number of terminals required, this must be balanced against other system requirements. Note that the CB terminal solution will always require a greater number of terminals than the IB system because of the lower capacity per unit area of the CB. See Figure 5 for a comparison of a typical chilled beam zone layout with a typical induction beam layout.

The all-way blow IB design located in the center of a large room will result in the most even temperature distribution throughout the space compared to CB and VAV technology, require fewer terminals of larger capacity, and achieve the most economical layout of ductwork and piping. If noise becomes an issue, or air throw is too short to reach the limits of the covered area, consider placing two units along the centerline axis of the zone parallel to the exterior wall, located at the quarter-points of that line. For smaller rooms, one-way blow is preferable to two-way blow because it gives the best and most flexible air distribution options. Two-way blow terminals often result in a less uniform distribution within the room.

### Zone Layout – Chilled Beams 4 – 2 x 8 Units



### Zone Layout – Induction Beams 2 – 4 x 4 Units



Example: Typical Classrooms, 24' x 38' = 912 ft² of ceiling area

Figure 5 – Comparison of Chilled Beam System Zone Layout with Induction Beam System Zone Layout

## DESIGN CONSIDERATIONS

### Comfort and IAQ (Indoor Air Quality)

While we have focused on all of the “well-engineered” aspects of the Carrier induction beam system, it is important not to compromise our engineered comfort objective.

Comfort must be thought of as more than just controlling the zone sensible temperature and relative humidity within a set point range for occupant satisfaction. Over the last two decades we have come to recognize that while comfort is the perceived foundation of indoor air quality, the equally important aspects of human health and productivity must be included and addressed by building designers. Even with a well-designed and executed building project there are many outdoor and indoor contaminant sources that impact IAQ. Dilution and filtration are key processes of an HVAC system that can address these issues. (See Figure 6.) Using a continuous-ventilation terminal, the IB system solution excels in the contaminant

dilution area and provides excellent central equipment filtration. The VAV system solution has similar central equipment filtration attributes, but does not perform dilution as well as the induction system. Filtration of the room recirculated air is minimal on induction terminals, while in VAV systems the central equipment can excel at filtration.

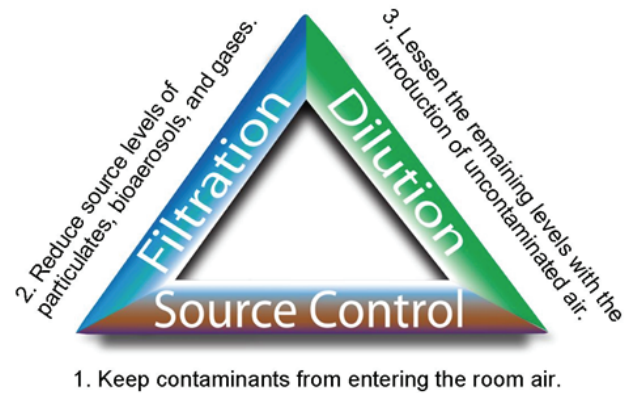


Figure 6 – HVAC Systems Improve Indoor Air Quality

## Acoustics

The temperature and humidity within the space are the major areas of concern for occupants, but following closely behind are noise (undesirable sound) and room air motion (draft) as the sources of the greatest number of complaints about workspaces.

Terminal performance can greatly impact each of these factors. Noise can be generated internally and created at the supply air diffuser. The method by which supply air is introduced into the occupied space also determines if air motion complaints might occur. Carrier's induction beam products (Figure 7) are extremely quiet, with NC values easily maintained at or below NC 30, meeting the requirements of even the quietest spaces in offices, schools and healthcare facilities. The all-way blow design coverage of large areas also assures limited concern over opposing airflows from adjacent terminals colliding and entering the occupied space at too high a velocity.

Properly sized VAV terminals with good Coanda effect diffusers laid out well will also exhibit good acoustic and air motion characteristics. Chilled beam terminals similarly require careful selection and layout to assure a quiet, comfortable design.

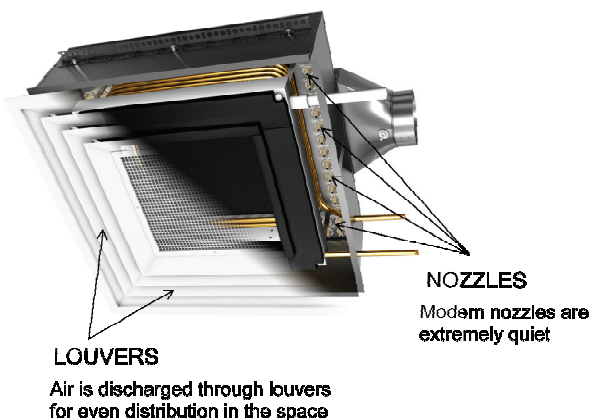


Figure 7 – Modern IB Terminal Features

## Mechanical Room and Distribution

For all three of the systems described in this paper, the non-terminal equipment can be located on a rooftop, in a penthouse, or within a formal mechanical equipment room (MER). Regardless of the location chosen, accommodations for proper maintenance and good locations for outdoor air intakes must be considered.

For all the solutions discussed here, the use of water piping and pumping at the central equipment indicates the preference for a penthouse or MER

location. While VAV systems have the largest space requirement for ductwork (IB and CB terminals both only distribute ventilation air to the zones), induction solutions likely have the greatest piping and pumping space needs since they are usually 4-pipe systems. Chilled beam solutions have often become quite complex in the MER in an effort to keep zone terminals condensate-free while still supplying 42 F to the primary air handlers. This complexity can exhibit itself in separate chillers for each CHWS (chilled water supply) temperature, or as complex mixing valve/bypass piping schemes, neither of which is required with the Carrier induction beam solution.

## Controls

Like many terminal-based systems, both induction and VAV systems have relatively simple zone controls. Capacity control is usually implemented through water valve and/or airflow damper modulation. Chilled beams have the additional requirement to avoid condensation on either the coil or the piping leading to it, so there is the added layer of dew point safeties involving moisture sensors either on the CHWS pipe at the terminal, or in the drip tray for those styles. In addition, chilled water plant control for CB systems is more complex since it must provide two temperatures of water, cold for the central air handler and above space dew point for the terminals.

Control for conditioning the primary air resides back at the central equipment and is quite similar for all three systems, though VAV can utilize an airside economizer, while induction systems are limited to waterside economizers. System-wide routines like scheduling and any set point resets would be part of an energy management system communicating with all HVAC system components, and are pretty similar for all three systems.

## SUMMARY

Ceiling-mounted induction beam zoning terminals are a modern update of Carrier's perimeter wall conduit induction terminals that brought air conditioning to urban-site skyscrapers of old. The engineered comfort features that made induction popular 50 plus years ago remain, and with lower primary air static pressure requirements the energy cost penalty has been addressed. Nozzle designs are now much quieter and higher capacity all-way blow terminals make for simpler layouts, keeping costs down and making integration with the dropped



ceiling less problematic. The new feature that makes modern induction beams a strong contender is the integrated drain pan and cooling coil design that allows room latent loads to be handled right at the zone. With the new induction beam terminal, the primary air does not have to be dehumidified to the lowest level required to handle the zone with the greatest need. Primary air does not need to be reheated before leaving the central equipment to prevent overcooling zones that are load-neutral.

No zone terminal solution is ideal for every situation, and induction is no different. In fact, most buildings have more than one type of terminal, creating a hybrid design that applies many good solutions to the many differing needs of the project. The induction beam terminal adds another offering to the list of potential solutions and is one that designers should investigate and consider applying to future projects.



turn to the experts<sup>SM</sup>



Carrier's AdvanTEC<sup>3</sup>C Solutions Center supports customers in developing strategic, energy-efficient and custom-engineered building solutions. This paper is provided for informational and marketing purposes only and shall not be deemed to create any implied or express warranties or covenants with respect to the products of Carrier Corporation or those of any third party.