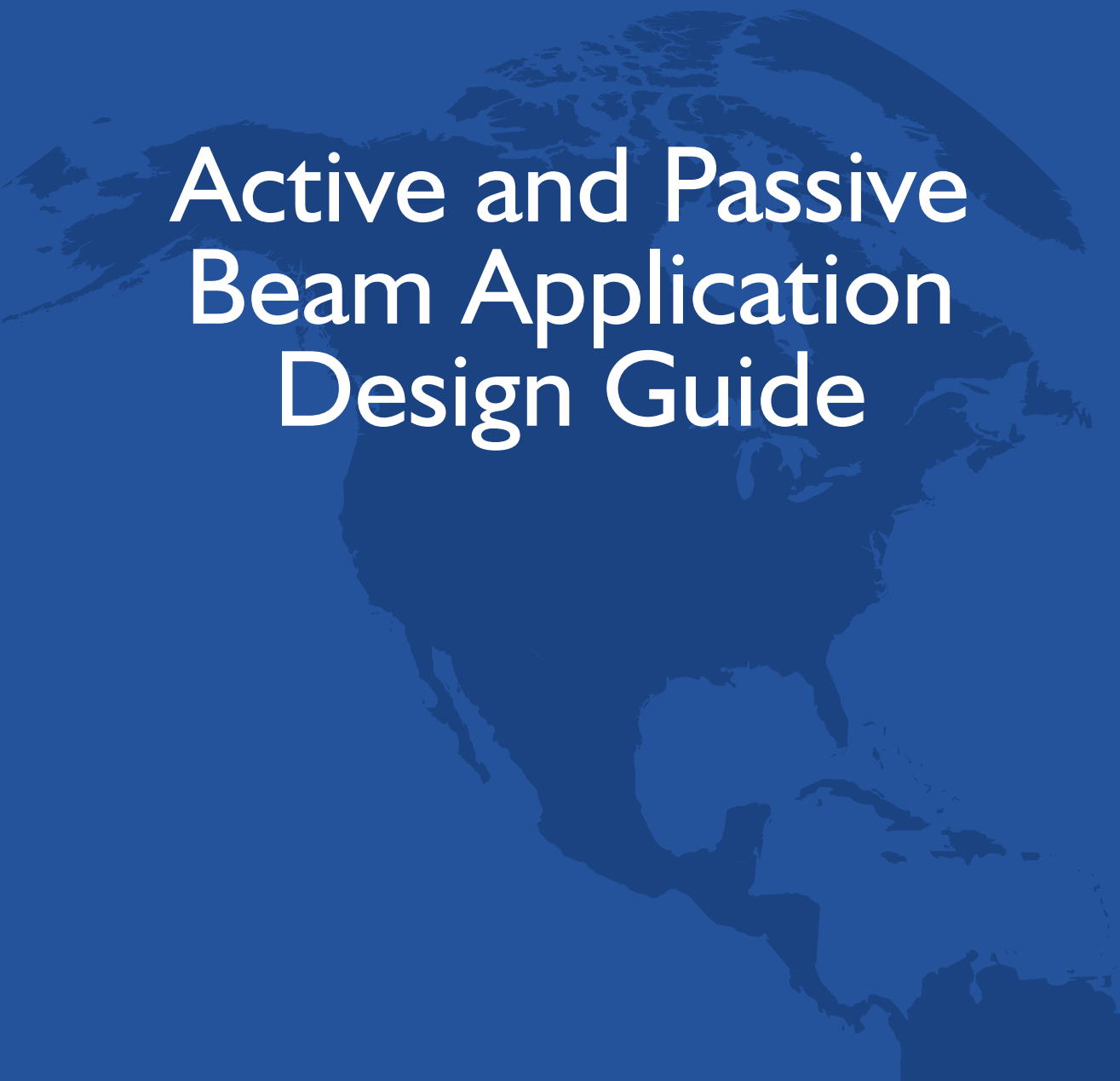
For Global Application

Active and Passive Beam Application Design Guide



REHVA

ASHRAE®

Joint publication of REHVA and ASHRAE

Active and Passive Beam Application Design Guide

This publication was developed under the auspices of ASHRAE Technical Committee (TC) 5.3, Room Air Distribution. TC 5.3 is concerned with the distribution, diffusion, and conditioning of air within rooms and similarly treated spaces. It includes consideration of the principles of air distribution, air diffusion, and performance characteristics of all types of air terminal devices, fan-coils, chilled beams, and high-/low-pressure assemblies (boxes) or components, including associated or related accessories for both supply and extract air.

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Updates/errata for this publication will be posted on the ASHRAE website at www.ashrae.org/publicationupdates.

Active and Passive Beam Application Design Guide



Atlanta



Brussels

ISBN 978-1-936504-83-1

© 2015 ASHRAE and REHVA

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Cover design by Tracy Becker

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Library of Congress Cataloging-in-Publication Data

Chilled beam application guidebook
Active and passive beam application design guide.
pages cm
Revision of Chilled beam Application Guidebook, published by REHVA, 2004.
This version has I-P units listed first.
Includes bibliographical references and index.
ISBN 978-1-936504-83-1 (softcover) 1. Chilled beams (Air conditioning) I. ASHRAE (Firm) II. Federation of European Heating and Airconditioning Associations. III. Title.
TH7687.78.C46 2015
697.9'312--dc23

2014043062

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CONTENTS

1 Preface and Acknowledgments	1
2 Terms and Definitions	2
3 Symbols and Units	3
4 Abbreviations	4
5 Introduction	6
6 Comfort	14
7 Passive Beams	16
8 Active Beams	25
9 Primary Airflow Calculation Methodology	35
10 Controls	44
11 Installation and Commissioning	54
12 System Operation	57
13 Energy and Total Cost of Ownership	58
14 References and Bibliography	61
Appendix A: Examples for I-P Applications	64
Appendix B: Examples for SI Applications	89

Excel files for beam calculations provided online at ashrae.org/beamcalc.



1 PREFACE AND ACKNOWLEDGMENTS

PREFACE

This design guide is a revision of the REHVA *Chilled Beam Application Guidebook*, which was published in 2004. ASHRAE and REHVA decided to collaborate on a revision of the guidebook and enlisted experts from both organizations to revise the document.

This new guide is aimed at consulting engineers, architects, owners, and contractors who are involved in the design, operation, and installation of active and passive beam systems.

This book provides tools and guidance to design, commission, and operate active and passive beam systems to achieve a determined indoor climate. It also presents examples of active and passive beam calculations and selections. Online tools can be found at ashrae.org/beamcalc.

ACKNOWLEDGMENTS

There are many ASHRAE and REHVA members who should be recognised for their expertise in realizing this design guide.

The following ASHRAE and REHVA experts should be recognised for their diligent help, guidance and collaboration in producing this design guide.

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2 TERMS AND DEFINITIONS

The following terms and definitions are based on the CEN and ASHRAE standards for testing and rating of chilled beams. Additional definitions are mainly from the ISSO publication *Climatic Ceilings and Beams: Applications of Low Temperature Heating and High Temperature Cooling* (2001).

active beam: a terminal device with an integrated, ducted air supply that induces ambient air through a hydronic coil for the purpose of transferring sensible heat to/from the space.

dew point: the temperature at which water vapour present in the air begins to condense.

draught: unwanted cooling of the body caused by local air movement.

draught rating (DR-value): the percentage of people predicted to be dissatisfied due to draught.

induced airflow: the secondary airflow from the room induced by the primary air in an active beam.

induction ratio (IR): the volume or mass flow rate of induced air (sum of the primary and secondary air) divided by that of the primary air. *IR* equals $(Q_p + Q_s)/Q_p$.

infiltration: the transport of unconditioned air through leakage paths in the envelope of a building, resulting from pressure (e.g., wind) and temperature differences.

mixed airflow rate: the total airflow rate (primary plus induced) of the mixture supplied from the beam to the space.

mean radiant temperature: the theoretical uniform temperature of a room in which the radiant exchange between the human body and its environment is the same as the radiant exchange in the actual location.

passive beam (static beam): the cooled element or cooling coil fixed in, above, or under a ceiling fitted with a cooling coil, that cools mainly convectively, using natural airflows. The cooling medium is usually water.

primary airflow rate: conditioned air supplied to an active beam through a duct from the air-handling unit.

room air temperature: the average of air temperatures measured at 3.61 ft (1.1 m) high, positioned out of the main air current from the beam.

turbulence intensity: the ratio of the standard deviation of the air velocity to the mean air velocity. Used to measure variations in air velocity.

3 SYMBOLS AND UNITS

Symbol	Quantity	Unit: I-P (SI)
c_p	specific heat capacity, c_p = 1 Btu/lb$_m$°F (4.187 kJ/[kg·K]) water, c_p = 0.24 Btu/lb$_m$°F (1.005 kJ/[kg·K]) air	
L	active length of beam	ft (m)
L_t	total length of a beam, including casing	ft (m)
P	total cooling capacity active beam, $P = P_a + P_w$	Btu/h (W)
	total cooling capacity passive beam, $P = P_w$	Btu/h (W)
P_a	primary air cooling capacity, $P_a = Q_p \rho_p c_p (t_a - t_p)$	Btu/h (W)
P_L	specific cooling capacity of a beam, relative to active length L	W/ft (W/m)
P_{LN}	nominal specific cooling capacity at Δt_N	Btu/h·ft (W/m)
P_N	nominal cooling capacity at Δt_N	Btu/h (W)
P_w	water-side cooling capacity, $P_w = c_p \cdot Q_m (t_{w2} - t_{w1})$	Btu/h (W)
q	thermal load	Btu/h (W)
Q_m	water mass flow rate ($Q_m = \rho_w \cdot Q_w$)	lb/min (kg/s)
Q_p	primary airflow rate	cfm (m³/s)
Q_s	secondary airflow rate	cfm (m³/s)
Q_w	water flow rate	cfm (L/s)
t_a	induced air temperature	°F (°C)
t_p	primary air temperature	°F (°C)
t_r	reference air temperature = room air temperature	°F (°C)
t_{w1}	water inlet temperature	°F (°C)
t_{w2}	water outlet temperature	°F (°C)
t_w	mean water temperature, $t_w = 0.5(t_{w1} + t_{w2})$	°F (°C)
W	humidity ratio (mass water/unit mass dry air)	lb/lb (kg/kg)
Δt	temperature difference, $\Delta t = t_r - t_w$	°F (K)
Δt_N	nominal temperature difference	°F (K)
ρ_p	density of primary air, 0.075 lb/ft^3, 70°F (1.20 kg/m^3, t = 21°C)	lb/ft^3 (kg/m^3)
ρ_w	density of water 62.4 lb/ft^3 (1000 kg/m^3)	lb/ft^3 (kg/m^3)

4 ABBREVIATIONS

A	floor area
ACH, ach	air changes per hour
ACH_{INF}	infiltration air changes per hour
AHU	air-handling unit
C_{air}	cooling by air (primary airflow)
CAPEX	capital expenditure
CHWR	chilled-water return
CHWS	chilled-water supply
C_W	cooling by water (water coil)
CWT_{in}	Beam chilled-water temperature in
DB, db	dry-bulb temperature, °F (°C)
DB_{IDA}	IDA design condition cooling
DB_{ODA1}	ODA design condition cooling
DB_{ODA3}	ODA design condition heating
DB_{SUP}	primary air temperature
DCV	demand-controlled ventilation
DP	dew-point temperature, °F (°C)
DP_{IDA}	IDA design condition cooling
DP_{ODA2}	ODA design condition dehumidification
DP_{SUP}	primary air dew point
DR	draught rating
dT	temperature difference
Enth	enthalpy, Btu/lb (kJ/kg)
h	ceiling height
HR	humidity ratio, lb moisture/lb dry air (g moisture/kg dry air)
HR_{IDA}	IDA design condition cooling
HR_{ODA1}	ODA design condition cooling
HR_{ODA2}	ODA design condition dehumidification
HR_{SUP}	primary air humidity ratio

HWR	hot-water return
HWS	hot-water supply
INF	infiltration airflow
LCC	life-cycle cost
L_{LAT}	latent load (dehumidication dsg cdts)
L_{SENS}	sensible load (clg design cdts)
$MCDB_{ODA2}$	ODA design condition dehumidification
$MCWB_{ODA1}$	ODA design condition cooling
NP	occupancy
OCP_L	occupant load, lat/p
OCP_S	occupant load, sens/p
OPEX	operating expenditure
OPR	owner project requirements
PICV	pressure-independent control valve
PMV	predicted mean vote
PPD	predicted percentage of dissatisfied
R_a	ventilation, cfm/ft^2 (L/s·m^2)
RH_{IDA}	IDA design condition cooling
R_p	ventilation, per person
SET	standard effective temperature
TCO	total cost of ownership
V	primary airflow
V1	ventilation requirement
V2	airflow for dehumidification
vol	volume
w.c.	water column
WB, wb	wet-bulb temperature, °F (°C)

5 INTRODUCTION

Active and passive beam systems are an energy-efficient solution for spaces that require individual zone control and where the internal moisture loads are moderate. Active and passive beam systems provide good thermal comfort and energy and space saving advantages. The operation of the system is simple, with low maintenance requirements. Although they are often referred to as "chilled" beams, in many cases active beams can be used for both heating and cooling the space. In this guide, we will refer to them as active or passive beams.

Active and passive beams are room air recirculation devices that transfer sensible heat to and from the space using water. In addition, conditioned primary air is ducted to active beams. This primary air must satisfy the ventilation and latent requirements of the space and drive the induction of room air through the beam's coil. In the case of passive beams, this primary air is delivered to the space through a decoupled ventilation system. Active and passive beams may be integrated with acoustic ceilings or independently mounted.

5.1 COMMON APPLICATIONS

Active and passive beam systems have specific applications. As a result, each application must be reviewed for potential benefits as well as the suitability of these types of systems. One consideration that can assist in the decision to use hydronic systems, as opposed to an all-air system, is the air-side load fraction, or the percentage of the total air supply that must be delivered to the zone to satisfy code and possible dehumidification requirements. Tables 5-1 and 5-2 show typical load fraction for several spaces. The best applications for beam systems are those with the lowest air-side load fraction, because they are the ones that will benefit the most from the efficiencies of hydronic systems. Another factor that should be evaluated is the sensible heat ratio (the percentage of the cooling load which is sensible). To prevent latent removal by the hydronic system, the latent loads must be satisfied with an air system that will potentially offer some sensible cooling at the same time because of the temperature of dehumidified air. If the total sensible cooling load is significantly higher than the capacity of the air that would need to be supplied to satisfy the latent loads, a beam system might be a good choice.

5.1.1 Commercial Office Buildings

In an office building, active and passive beam systems provide several benefits. The reduced supply air volume required from the air-handling system for ventilation purposes provides significant energy savings. In addition, the smaller infrastructure required for this reduced airflow allows for smaller plenum spaces and mechanical room footprints, translating into shorter floor-to-floor construction or higher ceilings and increased usable floor space. The reduced supply air volume and elimination of fans at or near the space offers a significant reduction in generated noise. The minimized airflow often translates to reheat requirements being reduced. Figure 5.1 shows a typical office installation.



FIGURE 5-1 Active beams installed in an acoustical ceiling grid. Courtesy: Halton Oy

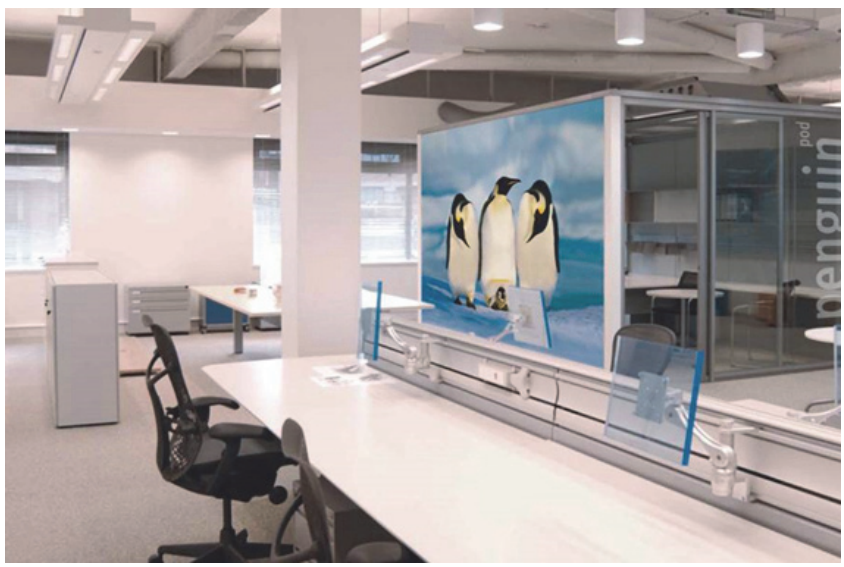


FIGURE 5-2 Exposed active beams in a commercial application. Courtesy: Halton Oy

TABLE 5-1 Typical Ventilation Rate for Difference Spaces According to ASHRAE/EN Standards

2007 and 2010 ASHRAE Standard 62.1 Occupancy Category	Default Occupant Density, ft²/Occupant		ASHRAE 62.1 Ventilation				Default Ventilation, cfm/person	Default Ventilation, cfm/ft²	2010 ASHRAE LEED v2 EQc2—Increase Ventilation Requirements	
	ASHRAE Standard 62.1, Number/1000 ft²	ASHRAE Standard 62.1	R_p, cfm/person	R_a, cfm/ft²	Default, cfm/person	Default, cfm/ft²	ASHRAE Standard 62.1	ASHRAE Standard 62.1	Rate, cfm/ft²	Governing Standard
Daycare (through age 4)	25	40	10	0.18	17	0.43	17	0.43	**0.56**	ASHRAE Standard 62.1
Classrooms (age 9+)	35	29	10	0.12	13	0.46	13	0.45	**0.59**	ASHRAE Standard 62.1
Lecture classroom	65	15	7.5	0.06	8	0.52	8	0.52	**0.68**	ASHRAE Standard 62.1
Lecture hall (fixed seats)	150	7	7.5	0.06	8	1.20	8	1.2	**1.56**	ASHRAE Standard 62.1
Multiuse assembly	100	10	7.5	0.06	8	0.80	8	0.8	**1.04**	ASHRAE Standard 62.1
Restaurant dining rooms	70	14	7.5	0.18	10	0.70	10	0.7	**0.91**	ASHRAE Standard 62.1
Cafeteria/ fast-food dining	100	10	7.5	0.18	9	0.90	9	0.9	**1.17**	ASHRAE Standard 62.1
Conference/meeting	50	20	5	0.06	6	0.30	6	0.3	**0.39**	ASHRAE Standard 62.1
Office space	5	200	5	0.06	17	0.09	17	0.09	**0.12**	ASHRAE Standard 62.1
Retail	15	67	7.5	0.12	16	0.24	16	0.24	**0.31**	ASHRAE Standard 62.1
Mall common areas	40	25	7.5	0.60	9	0.36	9	0.36	**0.47**	ASHRAE Standard 62.1

5.1.2 Schools

Schools are another application that can benefit from active and passive beam systems. Similar to office buildings, the benefits of a reduced supply air volume to the space are decreased fan power, lower plenum height, reduced reheat requirements, and lower noise levels (often a critical design parameter of schools).

5.1.3 Hospital Patient Rooms

Hospitals are applications where the outdoor air volume required by local codes and guidelines for each space is often greater than the requirement of the cooling and heating load, because of air quality issues for patients care.

5.1.4 Laboratories

Active and passive beam systems can be suitable in sensible-load-driven laboratories where the supply airflow rate is driven by the internal gains (such as refrigerators, testing equipment, etc.) as opposed to the exhaust requirements. In these environments, it is not unusual to require a large air-change rate in order to satisfy the load, although significantly fewer air changes may be required by code.

TABLE 5-2 Typical Load Fractions for Several Spaces from Europe

Application	Total Air Volume, All-Air System, cfm/ft^2 (L/s·m^2)	Ventilation Requirement, EN 15251—Cat II / Low-Pollution Building, cfm/ft^2 (L/s·m^2)	Air-Side Load Fraction
Single office	1.4 (7)	0.3 (1,4)	0,20
Open-space office	1.3 (6,5)	2.0 (1,2)	0,18
Conference room	2.2 (11)	0.8 (4,2)	0,38
School	2.2 (11)	0.8 (4,2)	0,38
Kindergarten	1.8 (9)	0.8 (4,2)	0,47
Auditorium	2.5 (12,9)	2.0 (10)	0,77
Department store	2.2 (11)	0.3 (1,7)	0,16
Restaurant	2.0 (10)	1.1 (5,4)	0,54
Patient room	1.6 (8)	0.3 (1,6)	0,20

In these applications, the difference between the supply air volume required to manage the sensible loads and that required to meet the fume hood airflow requirements provides opportunity for energy savings through the application of active and passive beams. These savings are typically due to the reduction in fan power as well as the energy associated with treating the outdoor air, which, in the case of a sensible-load-driven lab, may be significant.

5.1.5 Hotels / Dormitories

Hotels, motels, dormitories, and similar buildings can also benefit from active and passive beam systems. Fan power savings often come from the elimination of fan coil units located in the occupied spaces, as a central air-handling unit can have a lower total specific fan power. It also allows for the elimination of the electrical service required for the installation of fan coil units, as well as a reduction in the maintenance of the drain and filter systems. The removal of these fans from the occupied space also provides lower noise levels, which is a significant benefit in sleep areas.

5.1.6 Limitations

There are several possible applications where humidity can be difficult to control, such as lobby areas, kitchens, natatoriums, and spaces where there is a large and/or variable latent load from occupants.

Entrance areas may see a significant short-term humidity load if they are not isolated in some way (revolving doors or vestibules). In these areas, if outdoor conditions are very humid, a choice of a complementary technology is ideal. This is also more likely if the building envelope has a high infiltration rate and the outdoor conditions are very humid.

5.2 BEAMS TYPES

5.2.1 Passive Beams

Passive beams are characterized by heat transfer from natural convection of room air across the hydronic coil. Natural convection as it relates to passive beams occurs because of buoyancy forces when the cooler surface of the heat exchanger comes in contact with warmer room air; the air cools, its density increases, and the heavier air moves downward into the space.

5.2.2 Active beams

Active beams are characterized by forced convection caused by induction of room air across the hydronic coil. This induction is created by primary air discharged through nozzles at high velocity. The discharge air through the nozzles induces room air, which is heated or sensibly cooled by the coil and then mixed with the primary air. It is recommended that the space ventilation requirements and latent space loads be controlled by the volume and moisture content of the primary air supply.

5.2.3 Multiservice Beams

Typical beam installations deliver air for ventilation and latent cooling, as well as provide heating or sensible cooling for temperature control. In some instances, these can incorporate other building ser-

vices, such as lighting, power, network cabling, PA, smoke detection, and fire suppression. This consolidation is typically investigated in order to minimize the disparate elements in the ceiling. These are referred to as multiservice beams and are available with both active and passive beam types.

5.3 BENEFITS OF ACTIVE AND PASSIVE BEAM SYSTEMS

5.3.1 Energy

The heat transfer capacity of water allows for a reduction in the energy used to transport an equivalent amount of heat as compared to an all-air system. These reductions can be achieved primarily through reduced fan energy. The higher chilled-water supply (CHWS) temperatures used with active and passive beam systems, typically around 58°F(14.5°C), provide many opportunities for reducing in energy use.

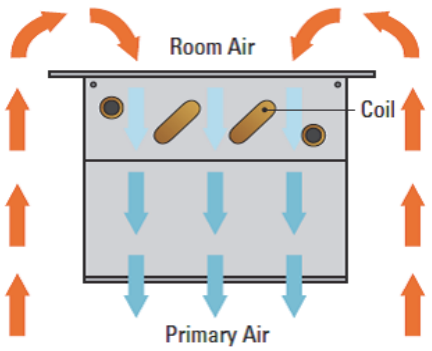


FIGURE 5-3 Airflow schematic of a passive beam.

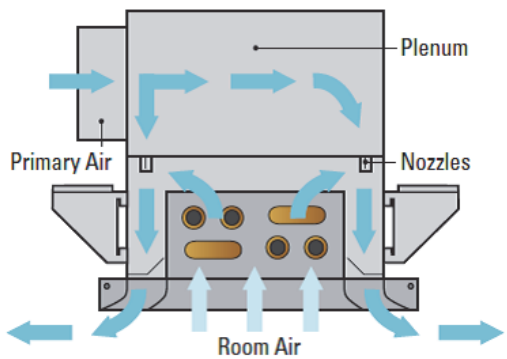


FIGURE 5-4 Airflow schematic of an active beam.

5.3.2 Beam Efficiencies

Water has a higher transfer efficiency than air because of its energy density characteristics per unit volume when transporting energy to and from a zone. It requires less power to move the necessary cooling or heating energy. Because the air volume for an all-air system has airflow volumes which are often significantly higher than ventilation requirements, larger ductwork is required to provide the same cooling or heating effect as the same unit volume of water (see Figure 5-6). The specific heat capacity per unit mass of water is 4.2 times higher than the specific heat capacity of standard air. The density of water is approximately 800 times greater than standard air.

5.4 CORRECTION FOR ALTITUDE

All psychrometric properties change with altitude, and this should be taken into account in the calculations and beam selection data.

Manufacturers' performance data, pressure losses, or sound power generated are usually valid for an air density of 0.075 lb/ft^3 (1.2 kg/m^3) at sea level. Air densities for different altitudes above sea, with correction factors, can be found in the *ASHRAE Handbook—Fundamentals*.



FIGURE 5-5 Exposed passive beams with integrated lighting. Courtesy: Trox

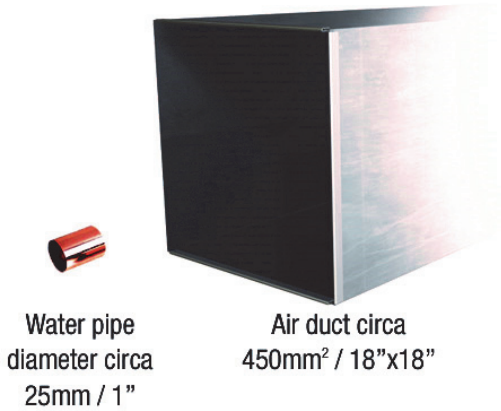


FIGURE 5-6 Approximate comparison between water and air transporting equivalent energy.

5.5 TESTING AND RATING

Testing of beams is done in accordance with EN 14518, *Ventilation for Buildings—Chilled Beams—Testing and Rating of Passive Chilled Beams* (ISO 2005b) (passive) and EN 15116, *Ventilation in Buildings—Chilled Beams—Testing and Rating of Active Chilled Beams* (ISO 2008) (active) in Europe. In the United States, the appropriate standard is currently under development, ASHRAE Standard 200P, *Methods of Testing Chilled Beams*, for active beams. Certification programs (Eurovent, AHRI) guarantee accuracy of manufacturers’ technical data.

6 COMFORT

6.1 THERMAL COMFORT

Human thermal comfort is defined as the state of mind that expresses satisfaction with the surrounding environment. Maintaining thermal comfort for occupants of buildings or other enclosures is the most important goal of HVAC design engineers.

Thermal comfort is affected by heat conduction, convection, radiation, and evaporative heat loss. Thermal comfort is maintained when the heat generated by human metabolism is allowed to dissipate, thus maintaining thermal equilibrium with the surroundings. Any heat gain or loss beyond this generates a perception of discomfort. It has been long recognised that the sensation of feeling hot or cold is not just dependent on air temperature alone.

Factors determining thermal comfort include the following:

- Personal factors
  - Clothing insulation level (Clo value)
  - Activity levels (metabolic rate)
- General factors affecting the whole body thermal sensation
  - Air temperature
  - Mean radiant temperature
  - Relative humidity
  - Air velocity

Thermal balance can, depending on activity and clothing, only be achieved within certain environmental conditions. For example, at temperature of 75°F (24°C), a person doing work sitting down in an office produces approximately 430 Btu/h (130 W) of total heat, of which 185 Btu/h (55 W) (ASHRAE 2009) is released through evaporation. The remaining heat is emitted through radiation and convection.

To assess whole body thermal comfort, a number of additional and derived quantities are used, such as operative temperature and radiant temperature asymmetry. To predict the statistical average of the space population's whole body thermal comfort, PMV and predicted percentage of dissatisfied (PPD) indices are used. To predict local thermal comfort, the draught rating (DR) index may be used. Refer to the examples in Chapter 10, Controls.

Standard EN ISO 7730:2005, *Ergonomics of the Thermal Environment—Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort* (ISO 2005a), and ANSI/ASHRAE Standard 55-2013, *Thermal Environmental Conditions for Human Occupancy,* define these indices and propose methods for predicting thermal sensation. The paramount consideration in sizing and locating the beams in the room should be maintaining thermal comfort within the occupied zone. The occupied zone is defined by EN 13779-2007, *Ventilation for Non-residential Buildings—Performance Requirements for Ventilation and Room-Conditioning Systems* (ECS 2007a), and ANSI/ASHRAE Standard 55-2013.

Indoor climate target values (normally specified in the owner's project requirements) should be taken into account when defining design values for beam systems. Specific capacity (by beam length) and primary airflow rate should be limited to the range where proper operation conditions and comfortable thermal conditions can be ensured (e.g., by avoiding objectionable velocities in the occupied zone or stratification).

Typical indoor climate target values are as follows:

- –0.5 < PMV < 0.5.
- Localized factors affecting specific exposed body area
  - Vertical air temperature difference between 3.6 and 0.33 ft (1.1 and 0.1 m) above the floor (level of head and ankles) <9°F (5°C)
  - Local air temperature
  - Air movement/velocity/turbulence
  - Radiant asymmetry

6.2 ACOUSTICAL COMFORT

Indoor sound level strongly influences human comfort. Bad acoustic design contributes to noisy environments, which can prevent spaces from being used for their intended purpose.

Room design sound pressure levels, generated and/or transmitted by the ventilation or air-conditioning system in different types of spaces, are defined in national standards. These values are time-averaged room sound pressure levels and apply to sound generated by the air-conditioning system only.

Sound sources, like active beams, generate sound power by airflow through the nozzles. Therefore, the sound power is strongly dependent on primary airflow.

7 PASSIVE BEAMS

7.1 PRACTICAL GUIDELINES

Passive beams provide sensible cooling from the water coil. Heating and ventilation must be handled by complementing systems.

Positioning of passive beams is crucial for the following:

- Capacity
  - Locating the passive beams in consideration of natural movement of room air can optimize beam output.
  - Avoid strong heat sources located directly below a passive beam.
  - Care should be taken to not locate a passive beam too far above the finished floor, as the cool convective air may not penetrate the occupied zone because of heat gain from room air or surfaces. Typical height above the finished floor is 15 ft (<4,5m). More detailed analysis is required to verify performance.
- Comfort
  - The higher the capacity per unit length, the more important the positioning becomes to maintain acceptable comfort (because of the potential of draught sensation).
  - Use areas outside the occupied zone to allow the cooled air to mix with the room air before it reaches the occupants.

7.2 FUNCTION

A passive beam consists of a coil and a casing (Figure 7-1). In some cases, it can include an architectural cover plate such as a perforated face or grille. The coil includes a circuit of copper

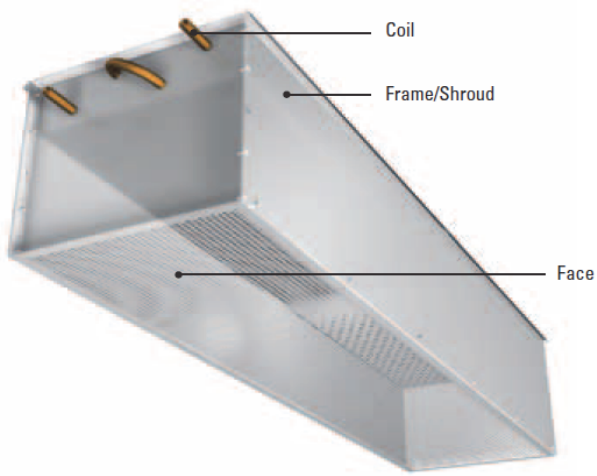


FIGURE 7-1 Typical construction of passive beam.