



*Photo 1: The Tahoe Center for Environmental Sciences in Incline Village, Nev., is the first laboratory in the United States to use chilled beams to eliminate reheat.*

# Chilled Beams in Labs

## Eliminating Reheat & Saving Energy on a Budget

By **Peter Rumsey, P.E.**, Member ASHRAE; and **John Weale, P.E.**

In laboratories, the use of active chilled beams, also called induction diffusers, allows designers to decouple ventilation requirements from sensible heating and cooling functions. If applied carefully and thoughtfully, this strategy can dramatically reduce both reheat energy and air-handling system size. In a recent laboratory project where active chilled beams were used, the size of outside air handlers and ductwork was reduced by 40%, and reheat was eliminated completely.

Chilled beam systems are prevalent in Europe, but are not yet widely known or used in the U.S. (although their use is increasing gradually as designers become more aware of their benefits). So far their use has been largely confined to commercial buildings, where their low investment costs and high cooling capacity offer compelling benefits.

This article addresses how chilled beams work; how to apply them in laboratories; and the specific benefits (and

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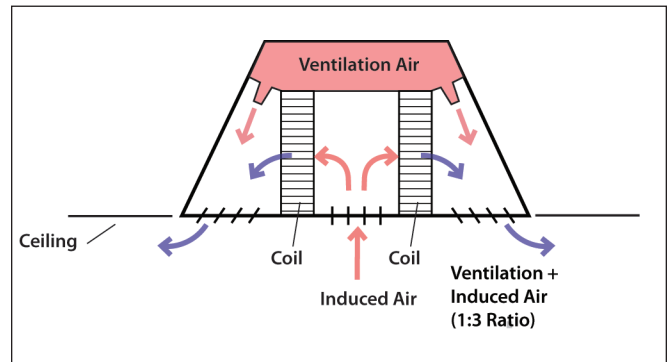
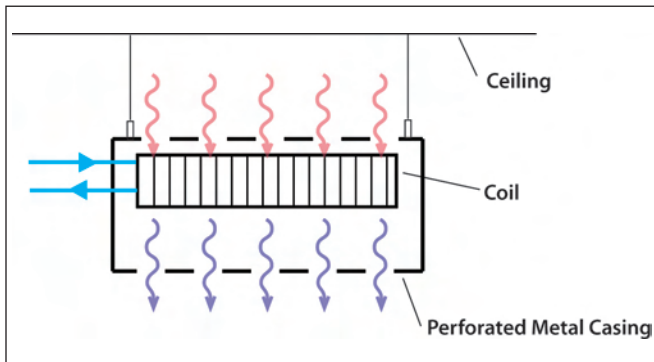


Figure 1 (left): Passive chilled beam. Figure 2 (right): Active chilled beam.

limitations) of their use in laboratories. It also presents a representative case study where they've been used successfully.

### How Chilled Beams Work

A chilled beam is a device that is located in or directly above the conditioned space and works in a fundamentally different way than the all-air diffusers used in most U.S. buildings. Two basic chilled beam types are in use: passive and active. Passive chilled beams usually consist of a small coil in a box that is recessed in the ceiling or hung from the ceiling. They are used for cooling and depend on natural convection. Chilled water flows through the coil and the air around the coil is cooled and falls into the room, driven by convection (Figure 1).

As with passive chilled beams, active chilled beams have coils in ceiling-mounted boxes. However, active chilled beams use ventilation air that flows through the diffuser. The ventilation air is introduced into the diffuser box through small air jets, which induce room air to flow through the coils (Figure 2). Because the active introduction of ventilation air magnifies the natural induction effect, active chilled beams are also commonly referred to as induction diffusers. This induction effect gives active chilled beams much higher cooling or heating capacities than passive chilled beams.

Despite the fact that chilled beams have lower capacities than standard air diffusers and take more ceiling space (Table 1), they can enable dramatic reductions in the air-handling systems required for laboratories. Sensible heating and cooling are decoupled from the ventilation and humidity control functions, and ventilation is the only remaining purpose of the air-handling system. In office buildings, ventilation-only air-handling systems are 20% to 30% smaller than all-air cooled systems.

Two critical strategies that need to be addressed when designing with chilled beams are 1) using warmer than normal chilled water and 2) controlling humidity in the conditioned space. If standard 45°F (7°C) chilled water is used in chilled beams, there is a risk of condensing water on the coil in the diffuser. To prevent such condensation, room humidity must be actively maintained below 50°F to 55°F (10°C to 13°C) dew point or 50% to 55% relative humidity at 72°F (22°C). Relative humidity is controlled through the ventilation or air supplied to the diffuser. Also, chilled water needs to be supplied to the

chilled beam at least 3°F or 4°F (1.7°C or 2.2°C) above the room dew point. Therefore, most chilled beams use chilled water in the 55°F to 60°F range (13°C to 16°C). As an extra measure of safety, some chilled beam configurations include drip pans that are large enough to hold a minimal amount of condensate. However, if properly controlled by careful design, condensation issues can be prevented.

Many new office buildings in Europe use chilled beams, and all major European HVAC equipment manufacturers produce chilled beam products. Europeans like active chilled beams in office buildings because they allow the ducting to be significantly smaller, as it only carries ventilation air, and cooling is accomplished through chilled water in the induction diffusers. Smaller ducting allows for lower floor-to-floor heights and less building skin. Active chilled beams are beginning to be specified for a few significant U.S. projects, including several new laboratory facilities.

### Chilled Beams in Laboratories

HAVC requirements for laboratory facilities are fundamentally different from those of commercial office spaces. Chilled beams provide even more compelling benefits for laboratory facilities than for office spaces. Laboratories require a fixed amount of ventilation air to maintain safety, but air change rates, size of ducting and air handlers are all typically determined by cooling loads. In most labs, air systems can be dramatically reduced if chilled beams are used to handle the cooling requirements and ventilation air is the only air supplied to the room through active chilled beams. Active chilled beams are not appropriate for every laboratory and do present some limitations (see *Potential Drawbacks and Limitations* section). However, if applied thoughtfully, they can offer many other benefits, as described next.

#### Reduced Ducting and Air-Handling Systems

Ventilation requirements for safety in labs are usually in the range of six to 10 air changes per hour. However, many labs are designed for higher air change rates to accommodate high fume hood counts and high cooling loads. Typical lab equipment cooling loads range between 5 to 15 W/ft<sup>2</sup> (54 to 162 W/m<sup>2</sup>). When cooling loads from people, lights and the building shell

Diffusers	Size	Air Delivered To Space	Chilled Water (gpm At 55°F)	Sensible Cooling Delivered (Assumes 75°F In room)
Standard: All Air Diffusers	2 × 2	250 cfm at 55°F	None	5,400 Btu/h
Passive Chilled Beam	2 × 4	0	0.5 gpm	1,200 Btu/h
Active Chilled Beam	2 × 4	95 cfm at 68°F	1.5 gpm	4,600 Btu/h

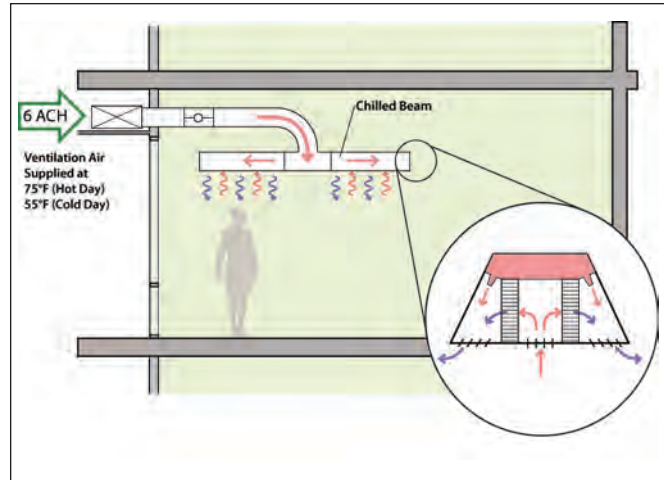
**Table 1: Comparison of cooling delivery capacities.**

are factored in, the typical range is 10 to 20 W/ft<sup>2</sup> (108 to 215 W/m<sup>2</sup>). As seen in Table 2, the maximum air change rate is most commonly determined by the cooling load requirement. In some labs with extremely high fume hood counts, (more than four hoods per 1,000 ft<sup>2</sup> (93 m<sup>2</sup>) lab or 14 air changes per hour assuming a 10 ft [3 m] ceiling), air change rates can be dominated by fume hood flow. If active chilled beams are applied to laboratories where duct sizing and air handler sizing are driven by cooling requirements, significant savings are possible: in many cases, ducting can be downsized to handle less than half of the air. The savings realized from this design strategy can be used to pay for the piping and active chilled beam units. If modest reductions in floor-to-floor height due to smaller ducting are taken into account, using an active chilled beam system will translate into an overall savings in construction costs and significantly reduced operating costs.

#### Eliminated or Reduced Reheat

Another energy saving benefit that chilled beams offer is their ability to eliminate or reduce the need for reheat in labs. The standard lab system uses a VAV reheat scheme, which, due to widely varying equipment loads between labs served by the same system, wastes significant amounts of energy by cooling outside air and then reheating that air. In a typical laboratory facility with several labs, ventilation air must be cooled down to the temperature that will satisfy the lab with the highest heat load. With the proliferation of high heat load analysis equipment and low temperature freezers, the design supply air temperature (typically 55°F [13°C]) is used for most of the year. On cold days this is not a problem, but when outside air temperatures rise above 55°F (13°C), the ventilation air is cooled to meet the requirements of the most heavily loaded lab, then reheated for all the other labs that don't require as much cooling.

In many detailed energy analyses of labs, cooling air and then reheating it can easily account for 20% of annual HVAC energy costs. Active chilled beams allow for ventilation air to be supplied at 65°F or 70°F (18°C to 21°C). When air is supplied at 70°F (21°C) and all of the cooling is accomplished in the chilled beam's cooling coil, reheat is completely eliminated. In the case where 65°F (18°C) air is needed to increase the cooling capacity of the chilled beams, small amounts of reheat



**Figure 3: Schematic diagram of a chilled beam system.**

Total Cooling Load Including Lights, People, Building Envelope And Equipment	Required Air Change Rate For Safety (Air Changes Per Hour)	Air Change Rate for Cooling (Assumes 55°F Supply Air and 75°F Exhaust Air)	Air Change Rate Driven By:
10 W/ft <sup>2</sup>	6 ACH	9.4 ACH	Cooling
15 W/ft <sup>2</sup>	6 ACH	14.1 ACH	Cooling
20 W/ft <sup>2</sup>	6 ACH	18.8 ACH	Cooling
10 W/ft <sup>2</sup>	8 ACH	9.4 ACH	Cooling
15 W/ft <sup>2</sup>	8 ACH	14.1 ACH	Cooling
20 W/ft <sup>2</sup>	8 ACH	18.8 ACH	Cooling
10 W/ft <sup>2</sup>	10 ACH	9.4 ACH	<b>Safety</b>
15 W/ft <sup>2</sup>	10 ACH	14.1 ACH	Cooling
20 W/ft <sup>2</sup>	10 ACH	18.8 ACH	Cooling
10 W/ft <sup>2</sup>	12 ACH	9.4 ACH	<b>Safety</b>
15 W/ft <sup>2</sup>	12 ACH	14.1 ACH	Cooling
20 W/ft <sup>2</sup>	12 ACH	18.8 ACH	Cooling

**Table 2: Chilled beams are appropriate in labs where cooling is the driver of air-change rates.**

are needed in labs where cooling loads are small. Either way, significant cooling and heat cost reductions are possible.

#### Replacing Fan Energy with Pump Energy

The other energy benefit of active chilled beams is that cooling is accomplished with pumped chilled water instead of blown cold air. Water has a volumetric heat capacity 3,500 times that of air. In typical pump and fan arrangements, this translates into a reduction in fan energy by a factor of seven. On an annual basis, at least half of the cooling is accomplished by the coil in the chilled beam. The ramp-up of air in typical lab systems does not occur during high heat loads. Instead the pump provides chilled water into the chilled beam as needed for cooling. Depending on the baseline reheat coil design, there may be a small pressure drop penalty in the chilled beam of 0.25 to 0.5 inches of static pressure (62 to 125 Pa), but this is insignificant compared to the total fan energy of an air system usually operating in the range of 3 in. to 8 in. (747 to 2000 Pa)



of total static pressure. The small chilled beam pressure drop provides induction, so well over half the conditioning airflow can be drawn from the room and directly through the low face velocity beam coil, rather than being brought in from outside and driven through the entire supply system, which includes zonal pressure control devices, ducting, coils, filtration, and other equipment.

#### **Smaller Space Requirements**

Chilled beams can fit in tighter spaces, and eliminate the need for high-volume ductwork, making them highly adaptable to conditions where floor-to-slab height is minimal. Beams can be mounted directly below the ceiling slab, as no air gap is required between the beam and the ceiling. Compared to traditional all-air systems, the duct work reductions allowed by chilled beam systems can translate into floor-to-ceiling height reductions of 6 in. to 18 in. (150 mm to 460 mm). This results in lower building skin and structural costs.

#### **Free Cooling & Improved Chiller Efficiency**

Chilled beams *require* higher chilled water temperatures to avoid condensation. In most cases, chilled water temperatures are in the 55°F to 60°F (13°C to 16°C) range. These warmer temperatures enable water-side economizer or free cooling applications. If a chiller were dedicated to this cooling water, the resulting chiller efficiency improvement (compared to a chiller running at 40°F to 45°F [4°C to 7°C]) would be 15% to 20%. Some chiller capacity does need to be reserved for the lower temperature chilled water so that dehumidification is possible on warmer summer days. Often chillers are laid out so that they can be controlled to provide either temperature and, thus, back each other up. Warmer chilled water also allows chiller compressors to be smaller so that the purchase cost per ton or kW of cooling is lower and electrical support requirements are reduced.

#### **Potential Drawbacks and Limitations**

While active chilled beams present significant benefits, several drawbacks and potential pitfalls exist in their use that bear discussion and examination.

Some of the lessons learned in designing with active chilled beams in labs are highlighted next.

**Noise.** If too much air is pushed through a chilled beam, the noise of the induction nozzles can be noticeable and become a problem. It's best to avoid high flows by using an adequate number of chilled beams to reduce the required flow per beam.

**Size.** Active chilled beams come in a variety of sizes and capacities. The most common width is 2 ft (600 mm). The most economical length is 10 ft (2.5 m). If these larger sizes are used, ceiling grid coordination with lighting equipment can become an important consideration.

**High load rooms.** Active chilled beams have a maximum cooling delivery capacity. Manufacturer data is well-developed and allows the engineer to determine that capacity and the number of units needed. In labs where equipment loads are in the 20 W/ft<sup>2</sup> (215 W/m<sup>2</sup>) or higher range, their application can become impractical because too many chilled beams would be required. These more cooling-intensive rooms frequently require different design solutions, such as the use of fan coils. Note that with good shading of windows and skin design, the impact of outdoor air conditions on the *lab* load can be minimized, and equipment loads can become the dominant factor impacting chilled beam use, even in regions that require high cooling.

**Condensation.** Condensation is a legitimate concern and potential drawback of active chilled beams. In spaces where it's not possible to control the humidity of the supply or ventilation air, chilled beams may not be an optimal design solution. To avoid condensation, supply air dew point and room dew point sensors are required to ensure chilled water temperatures are maintained above the dew point. For additional safety, keeping a spread of 3°F to 5°F (1.6°C to 2.7°C) between the room dew point and the chilled water temperature will avoid all condensation conditions. An emergency shutoff that uses a moisture detector mounted on a vertical section of exposed pipe may also be a prudent safety measure to include.

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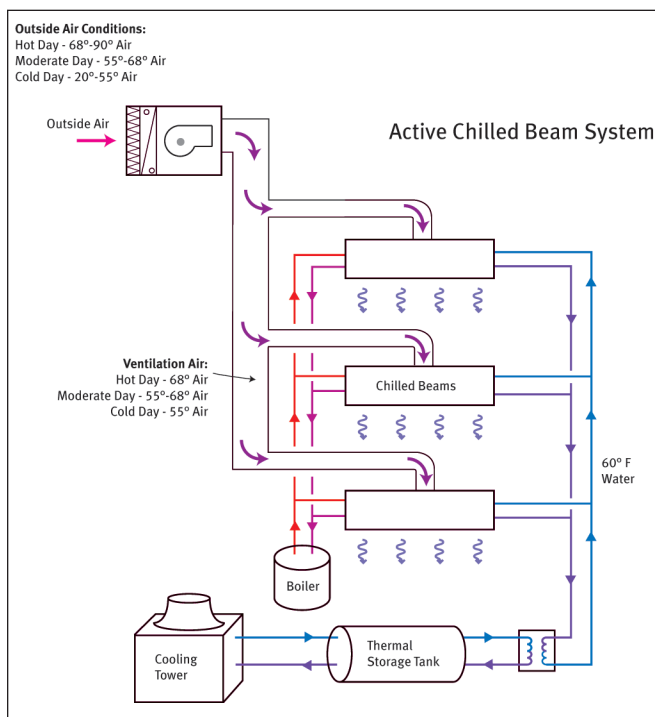


**Photo 2:** Chilled beam installation at the Tahoe Center for Environmental Sciences.

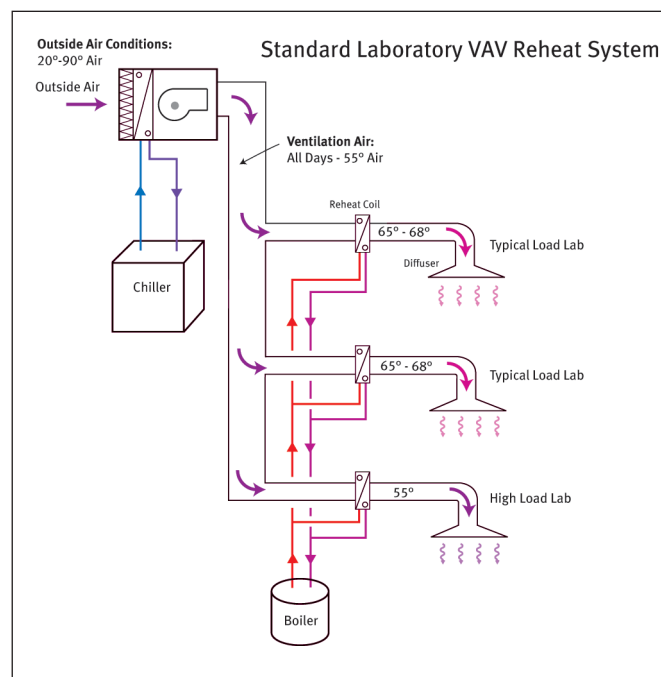
**Fume hood intensive rooms.** For labs with a high density of fume hoods, the benefits of active chilled beams are not as clear. In some cases, high safety airflow rates are required, ducts are sized already for the higher airflows, and savings from reducing ducting are not possible. If a building has only a few labs with a high density of fume hoods, chilled beams can still be feasible. In a lab facility where most of the labs have a high density of fume hoods, the main benefit of chilled beams would be in reducing reheat, but not ducting and air handler sizing. In cases like this, careful energy analysis will determine the viability of chilled beam systems, which should be evaluated alongside other four-pipe solutions.

**Cost.** Chilled beams are imported or custom ordered and, therefore, carry a premium cost. Also, U.S. contractors typically are not familiar with the technology, and may be prone to apply a premium cost to a project that includes chilled beams. However, reduced costs of ducting and air handlers can outweigh the high cost of chilled beams. In the next few years, we expect that chilled beams will be manufactured in North America, that contractors will become more familiar with technology and products, and that costs will decrease accordingly.

**Pressure drop.** The induction nozzles of chilled beams do have a pressure drop, usually in the range of 0.5 in. of static pressure or less (125 Pa or less). If care is not taken in selecting the chilled beams, the pressure drop can rise up to 1 in. (249 Pa). At this



**Figure 4:** Tahoe Center's active chilled beam system.



**Figure 5:** Standard laboratory VAV reheat system.

point, additional required fan energy can cancel any potential savings from pumping instead of blowing cooling, although reheat energy and construction cost savings will not be impacted.

**Airflow patterns.** As with any other diffuser, active chilled beams have distinct airflow patterns, which are not unlike linear slot diffusers. Care needs to be taken to consider these airflow patterns and their impacts on fume hood airflow. The active chilled beam works best when placed perpendicular to

the fume hood face, preventing airflow down the face of the hood. Ceiling grid coordination also can be simplified.

**Economization.** By reducing the outside air demand significantly, incorporation of economization does not necessarily occur by default, but may require engineering consideration. Free cooling is highly recommended to achieve economization savings superior to a standard air economizer. The medium temperature water used by chilled beams is well suited to a free cooling configuration, which eliminates electrical chiller use when chilled water (at 65°F [18°C]) for many chilled beam installations) can be produced directly by a cooling tower.

#### **Case Study: Tahoe Center For Environmental Sciences**

One of the first laboratories in the U.S. that uses active chilled beams, the Tahoe Center for Environmental Sciences (TCES), located in Incline Village, Nev., (HDD 7,591, CDD 100) opened in August 2006. This 40,000 ft<sup>2</sup> (3716 m<sup>2</sup>) research and teaching laboratory was built for studying the Lake Tahoe environment as a joint venture between the University of California, Davis and Sierra Nevada College. Ten thousand square feet (929 m<sup>2</sup>) of the building are dedicated to laboratory space.

The laboratory HVAC system uses active chilled beams in all of the labs except for two of the most cooling intensive labs, which use fan coils for peak cooling. The ventilation air is supplied at 68°F (20°C) when outside air temperatures are above 68°F (20°C). The active chilled beams use chilled water generated by a free cooling chilled water system. The 55°F to 60°F (13°C to 16°C) chilled water is then used to cool the labs as needed.

On cold days where outside air temperatures are below 55°F (13°C), outside air is heated to 55°F (13°C) and ventilation air is heated at each lab. When outside air temperatures are between 55°F and 70°F (13°C and 21°C), outside air is not treated and chilled beams provide heating and cooling as needed.

This strategy results in no reheat energy use. The minimum air change rates for ventilation and safety are six air changes.

The strategy of decoupling the ventilation system from sensible heating and cooling requirements allowed for a 33% reduction in the ducting and air handler sizing.

The most compelling aspect of this project was its cost impacts. There was a significant reduction in ducting, shafts, and air handler capacity. Due to high cost of the induction diffusers (they had never been used in Nevada, and contractors and regulatory agencies were unfamiliar with the product) the construction cost of this system was comparable to a standard mechanical system (*Table 3*). The design team did have difficulties with the design budget due to additional time spent analyzing the system as compared to standard systems. Further time was spent explaining and justifying the design to the owners and contractors.

Chilled beams made it possible to eliminate reheat and reduce the HVAC energy for the building by 57%. Several other strategies were integrated into the building. Some of these include: waste heat recovery from the exhaust air; a cogeneration system where waste heat is reclaimed for heating outside air; a 100% free cooling chilled water system that generates chilled water stored in tanks in cool evening hours; and a 30 kW photovoltaic system that covers 10% of the electrical demand of the building.

The Tahoe lab is in a climate that does not require as much cooling as many other climates in the U.S. In more challenging climates (more hours of heating and cooling) the reduction in outside air will result in further heating and cooling savings. In climates where more cooling is required, savings from reheat reduction will also be greater. Where significant dehumidification is required, savings from reducing reheat can be maintained by the use of a runaround coil that provides free precooling and free reheat in the ventilation air handler.

#### **Future Developments**

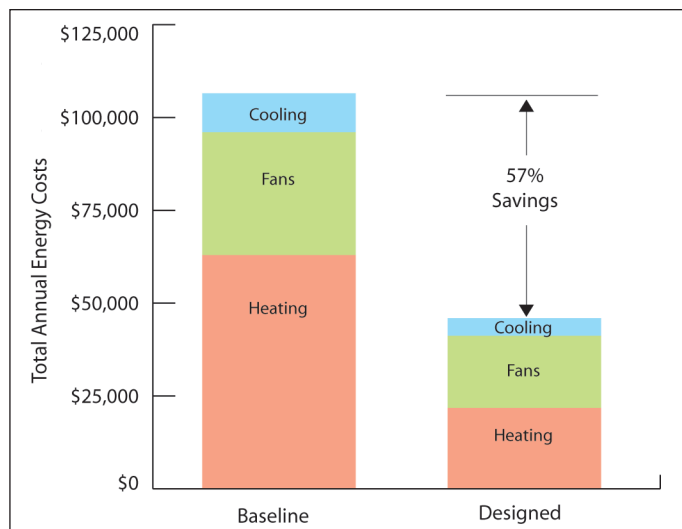
As chilled beams continue to evolve, many new developments look promising. First, the units themselves will begin to show more variety and flexibility in configuration, as the basic concept of the chilled beam can be seen more as a style of

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	Standard System Design	Active Chilled Beam Design
OA Air Handler Sizing	27,000 cfm	18,000 cfm
Ductwork	37,500 lb	30,000 lb
Exhaust Fan Capacity	27,000 cfm	18,000 cfm
Cooling System Capacity	35 tons	20 tons
Floor to Ceiling Height <sup>1</sup>	9 ft	10 ft
Mechanical System <sup>2</sup> Cost	\$741,000	\$722,000
1. Floor to floor height kept constant; active chilled beam allowed for ceiling to be raised 1 ft.		
2. Laboratory portion of the building is 10,000 ft <sup>2</sup> or 25% of the building. HVAC costs include laboratory systems only.		

**Table 3: Tahoe Center for Environmental Sciences' approximate cost comparison of chilled beam design vs. standard system design.**

**Figure 6: Tahoe Center for Environmental Sciences' baseline vs. designed estimated annual energy costs for cooling, heating and fans (based on DOE2 models, assuming \$0.11/kWh and \$1.03/therm).**



design than a specific proprietary product or technology. Second, chilled beams need to be engineered for the higher cooling loads typically seen in labs. If this were accomplished, fewer chilled beams would be required, simplifying ceiling coordination issues and lowering piping and component costs. Third, active chilled beams need to be designed with slightly different flow patterns when used in laboratory facilities. This would allow for more flexibility and prevent interference with fume hood airflow patterns. Fourth, and most importantly, active chilled beams need to be manufactured in North America instead of high cost Northern Europe. This would result in significant cost savings and make chilled beams affordable for many more labs and other building types.

## Conclusion

Active chilled beams have the potential of lowering both construction costs and energy costs in laboratory facilities. This contradicts the “received wisdom” that

more energy-efficient buildings cost more to build. Once this design strategy is further refined and demonstrated effectively, laboratory owners in the U.S. might want to at least consider the use of active chilled beams. As with any new technology, care and additional design time is required to ensure that all possible problems are avoided. Open discussion among engineers, contractors, and lab facility owners also will help to speed the successful adoption of this and several other energy-efficient strategies that are available to designers to lower costs and improve the performance of laboratory facilities.

## Acknowledgments

Passive and active chilled beam capacities in *Table 1* were derived using software provided by Trox USA. The TCES facility is designed by Lundahl and Associates, architects; Rumsey Engineers, HVAC and plumbing design; Integrated Design Associates, electrical design; and Dave Nelson Associates, lighting design. ●

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