ISSUES ARISING FROM THE USE OF CHILLED BEAMS IN ENERGY MODELS

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ABSTRACT

Chilled beam technology has seen increasing deployment throughout the United States during the past few years as designers seek the means to address larger sensible cooling demands without increasing duct sizes. While passive and active chilled beams work by basic principles well understood by engineers, their deployment in energy modeling software is often problematic or even erroneous. Active chilled beams have been the most commonly discussed type in the modeling community and our design experience has found these to be the most commonly applied as well. Active chilled beam model workarounds exist for the most commonly used simulation tools for the active chilled beams and tend to be based around induction units. Our experience has been that the magnitude of the simulated energy use results can seem reasonable, so many modelers stop there, though detailed review of hourly reports suggests that the various system components often aren't acting as the system is intended to operate. The perception of appropriate savings is just that, a perception, albeit misguided. This paper focuses on the differences of the design of actual chilled beam systems versus how they are modeled in eQuest, EnergyPlus, IES-VE, Trane TRACE, and TRNSYS rather than on the results of each software.

INTRODUCTION

Active chilled beams (ACB) are becoming more common in the built environment, and as such are finding their way into building energy models. Most software investigated had one or more significant issues with the way chilled beams were sized and operated that prevent the effective use of the model.

How Chilled Beams Work

An ACB works by supplying conditioned air (primary air) to the beam as shown in Figure 1. The air is then injected into the space via an array of nozzles that induce room air. The induced room air moves through the ACB where it is heated or cooled depending the needs of the space. The induced air mixes with the primary air, and enters the space (Loudermilk, 2009, Livchak, 2012). Note, the ACB can provide heating and/or cooling, and may be two pipe or four pipe.

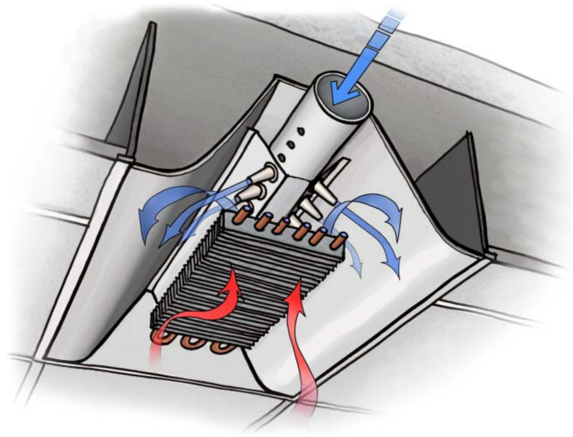


Figure 1: Active Chilled Beam Diagram.

How Active Chilled Beams are Operated

Most ACB are setup to operate in a constant air volume (CAV) configuration, but do have the ability to turn down as shown in the manufacturer's specificaitons. The issue of changing air flow rates is that the nozzles are sized for a particular air flow rate, and the induction ratio is a function of the air flow rate. Therefore, if the air flow changes, the induction ratio changes, and the performance of the beam changes.

Constant volume ACB typically include an air flow control terminal or damper upstream of the beam to maintain a certain air flow rate through the beam.

The chilled water supplied to the beam is at an elevated temperature, typically 57-60°F(13.9-15.6°C), as compared to the chilled water temperature supplied to the main air handling unit cooling coil, which is typically between 42-45°F (5.5-7.2°C). This requires a secondary chilled water loop to be included in the design, which may either be supplied by a separate chiller or a supplied off the main chilled water line and include a mixing valve to maintain the higher temperature. The higher temperature is critical as it reduces the chances of condensation forming at the chilled beam. Typically, ahumidity or dew point sensor is employed, and the chilled water temperature can be reset higher to provide additional assurances that the ACB will not sweat. This temperature difference requires a secondary chilled water loop to be included in the design, which may either be supplied by a separate chiller or supplied off the main chilled water line with a mixing valve to maintain the higher temperature.

Air handling unit configurations also vary for ACB applications and commonly include dedicated systems, central systems, or dedicated outside air systems (DOAS). When a large quantity of spaces, or common space types all have ACB, it may be economical to provide those zones with their own air handling unit (Figure 2). However, in larger buildings it may be more economical to have a larger central air handling system, which feeds zones with and without ACB (Figure 3). Another alternative is to have a DOAS which supplies a number of secondary air handling units, which in turn supply primary air to the ACB (Figure 4).

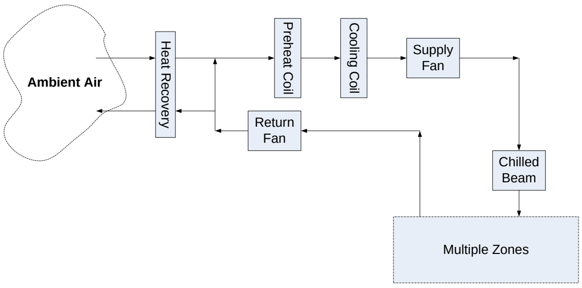


Figure 2: Dedicated AHU for Chilled Beams.

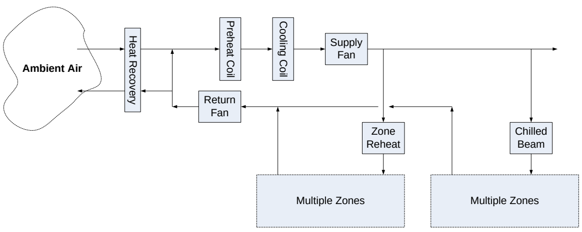


Figure 3: AHU Central Air Handling System with Chilled Beam.

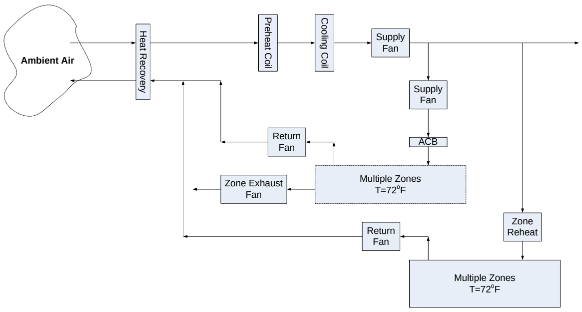


Figure 4: AHU DOAS Configuration.

To summarize, there are several factors working simultaneously that effect ACB performance and functionality that must be considered in an energy model to achieve realistic performance of an ACB.

MANUFACTURERS' DATA

Currently there is a limited amount of experimental data related to the performance of ACB for validation of modeling methods. To provide some insight into performance of ACB for design purposes, a review of manufacturer's performance data has been conducted in order to evaluate sensitivity of ACB devices to actual conditions. A survey of data provided by four manufacturers was conducted to determine the sensitivity of ACB performance to actual design parameters. Figure 5 shows the secondary air cooling capacity performance for a four foot (1.2m) long ACB at typical design conditions [57°F (13.9°C) entering chilled water temperature and 75°F (23.9°C) room air temperature]. The capacity among various manufacturer's shows a generally similar trend.

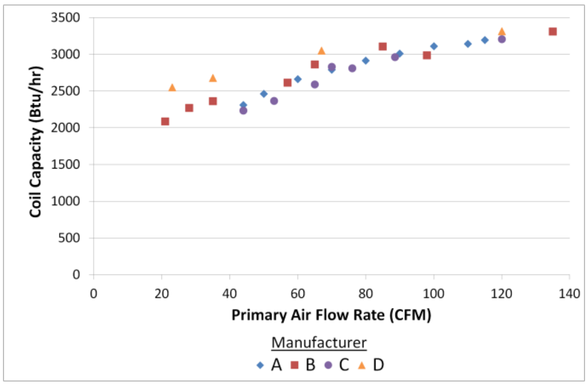
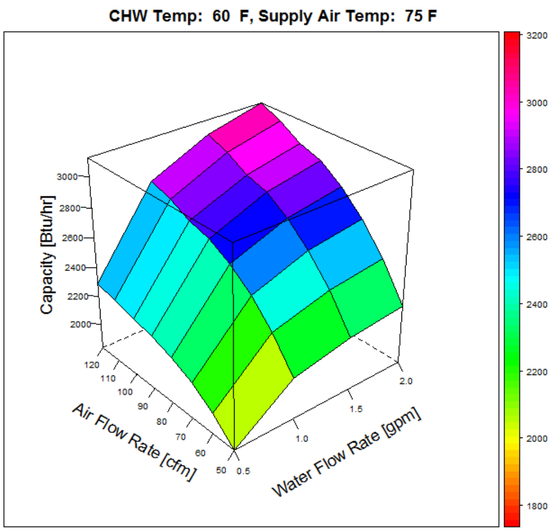


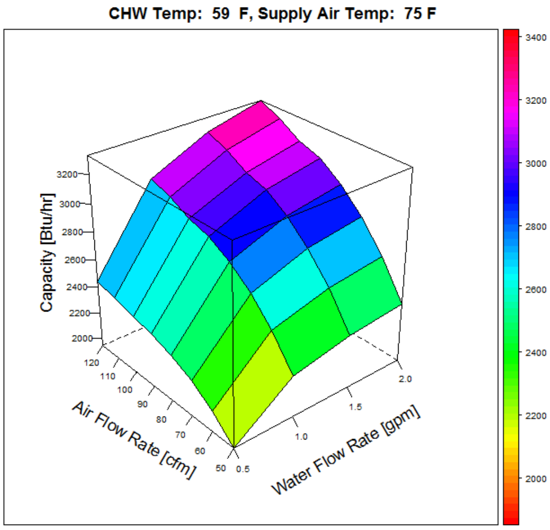
Figure 5: Comparison of Various Manufacturer's Chilled Beam Performance.

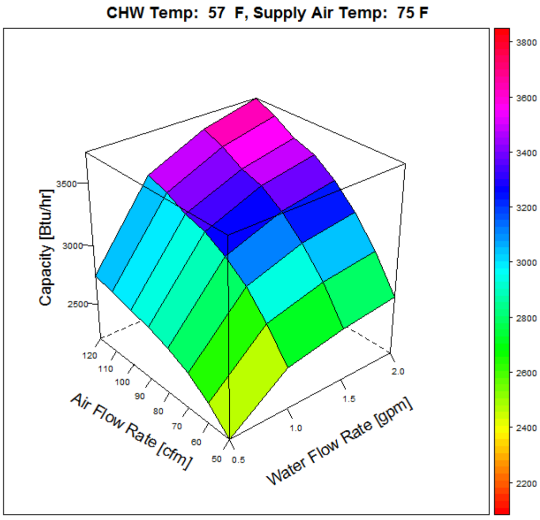
The actual secondary air cooling capacity performance of ACB devices is a function of several parameters, including primary air flow rate, entering chilled water temperature, room air temperature, and coil design parameters. The cooling capacity is based on manufacturer performance data for a single 4 ft long ACB is shown in Figure 6. Due to the fact that chilled beams are installed in discrete lengths (e.g. 3, 4, 6 ft) the capacity will vary for both design and part load operation.

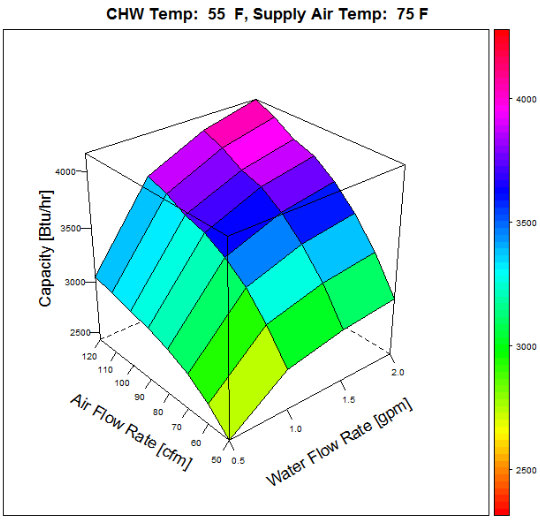
For a constant volume system an ACB model may be simplified from a 4-D dataset to a set of curves at the design air flow rate and chilled water temperature as a function of the chilled water flow rate and room air temperature. For empirically derived chilled beam models, this can alleviate difficulties with developing coefficients for all of the input parameters.

The output for a single chilled beam product can vary by 30% while still operating within reasonable design criteria. Additionally, the performance will vary nonlinearly during part load conditions. These effects need to be captured by the modeling program to accurately estimate air flow and pumping requirements and whether the zone loads are met by the system.









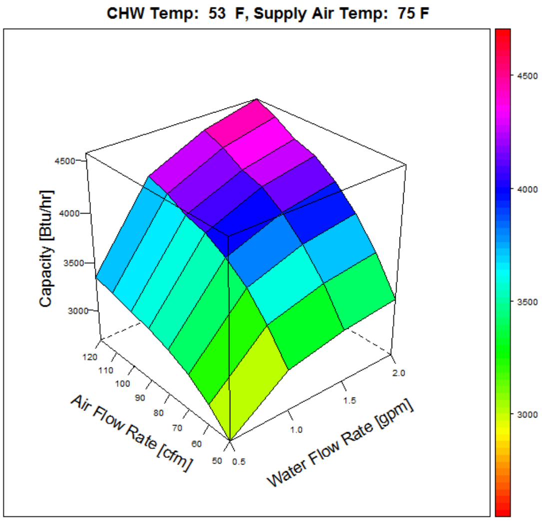


Figure 6: Example of ACB Performance for a Single Product.

SIMULATION

Several software were reviewed for this paper that include a variety of approaches to modeling active chilled beams including: eQuest 3.64b, Trane TRACE, IES-VE, EnergyPlus v7.0, and TRNSYS 17. Each software has pros and cons as to the approach to modeling ACB.

eQuest 3.64b

The typical approach to modeling chilled beams in eQuest is using an induction unit system. There are several issues that arise with modeling the induction unit (IU) systems in eQuest:

1. IU has a constant induction ratio.
2. There is limited humidity control at the zone level.
3. IU systems are only constant volume.
4. Air handling systems are rigid
    - Multiple terminal devices can’t be assigned to a single system, ie. no combination of standard diffusers, chilled beams, fan coils, etc.
    - Dedicated outdoor air system flow diagram is improper.
    - Multiple system chilled water loops do not work properly.
5. The approach temperature of chilled water and coil leaving air temperature is limited to 6°F (3.3°C)

Issue #1: The induction ratio is set at the system level and is constant regardless of airflow rate. As the IU system is constant volume, this is not a significant issue, however different zones may have different indution ratios in the real design. For example, ACB come in standard lengths, with a fixed peak capacity, however the air flow per room may not scale uniformly for different rooms with different functions. Therefore, it is possible to have different induction ratios at the zone level, while air is supplied from the same system.

Issue #2: There is limited control over humditiy as it is set at the system level, and is monitored in the return air stream. This tends not to be a problem as conditioned air is supplied to the zone, however if zones exist with significant latent load due to occupants it could be an issue. Care must be taken to verify no zone level dehumidifcation is taking place.

Issue #3: There is no workaround as the IU is a constant volume system, however this may or may not be a problem. For office, classroom, and other similar spaces, the goal of an energy efficient design would be to have mimimum ventilation air supplied to the chilled beam, which would translate to a constant volume system. A problem arises when a system needs more air for a few hours per year, but could otherwise operate at minimum ventilation air flow. eQuest will determine the maximum flow rate, and the IU will run at that flow rate year round. This leads to a large increase in fan energy consumption.

Constant volume spaces, such as patient rooms can work well if peak loads are controlled. A standard patient room requires a minimum of four or six air changes per hour depending on the code applied with two air changes per hour of outside air (ASHRAE 170-2008, UFC 4-510-01). An outside air quantity and a design air flow quantity can be input at the zone level, and should provide realistic results. Hourly reports should be referenced to verify that the proper air flows are being provided to each patient room.

Laboratories typically have nighttime air flow rate set backs, such as six air changes per hour during the day and four air changes per hour at night (Labs21). This type of setback cannot be modeled in eQuest when a chilled beam is applied. An average air flow could be used, however it will effect peak equipment sizing as most labs are 100% outside air. This also limits the use of variable flow fume hoods as they are forced to be constant volume as well in an IU system.

Issue #4: The AHU is likely the most significant issue in eQuest as it is not flexible enough to handle modern AHU designs with ACB. As shown in Figure 3, a single AHU may supply multiple space types with differing terminal devices. The work around for having multiple terminal devices is a dedicated outside air system (DOAS).

A DOAS is created in eQuest by creating a system that has its outside air supplied by another system. This strategy introduces a series of issues due to the flow diagram within eQuest. As shown in Figure 7, eQuest supplies the air to the IU system after the return fan, rather than after the supply fan, which does not correlate with the typical DOAS design shown in Figure 4.

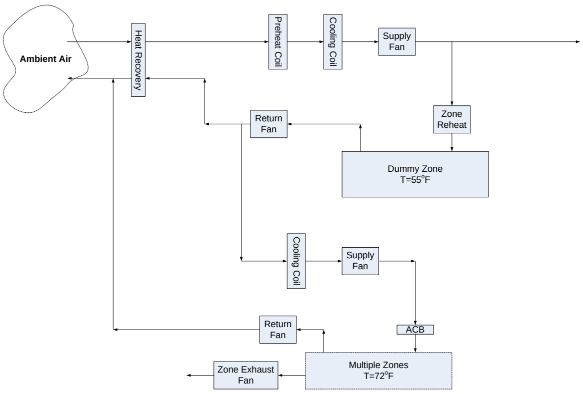


Figure 7: eQuest DOAS configuration.

secondary AHU with ACB is also 69°F (20.6°C), rather than 50°F (10°C) as would be desired.

A work around for this issue is to use a “Dummy Zone” (DZ), or a zone that is small, has no load, or air flow requirements such as an unconditioned space or storage closet. The setpoint temperature for this space is set to 55°F (12.8°C), which supplies the proper air temperature to the secondary AHU as shown in Figure 9.

As shown in Figure 7, the exhaust air (EA) from the secondary AHU is exhausted after the heat recovery unit. This is supported by Figure 9, which shows the DOAS EA Heat Recovery Inlet Temperature is the same as the DOAS Return Plenum Temperature rather than a mass based average between the DOAS Return Plenum Temperature and the Secondary AHU Return Plenum Temperature. Both systems are set to be 100% outside air, and have approximately the same flow rates. While it is possible to add a heat recovery unit to

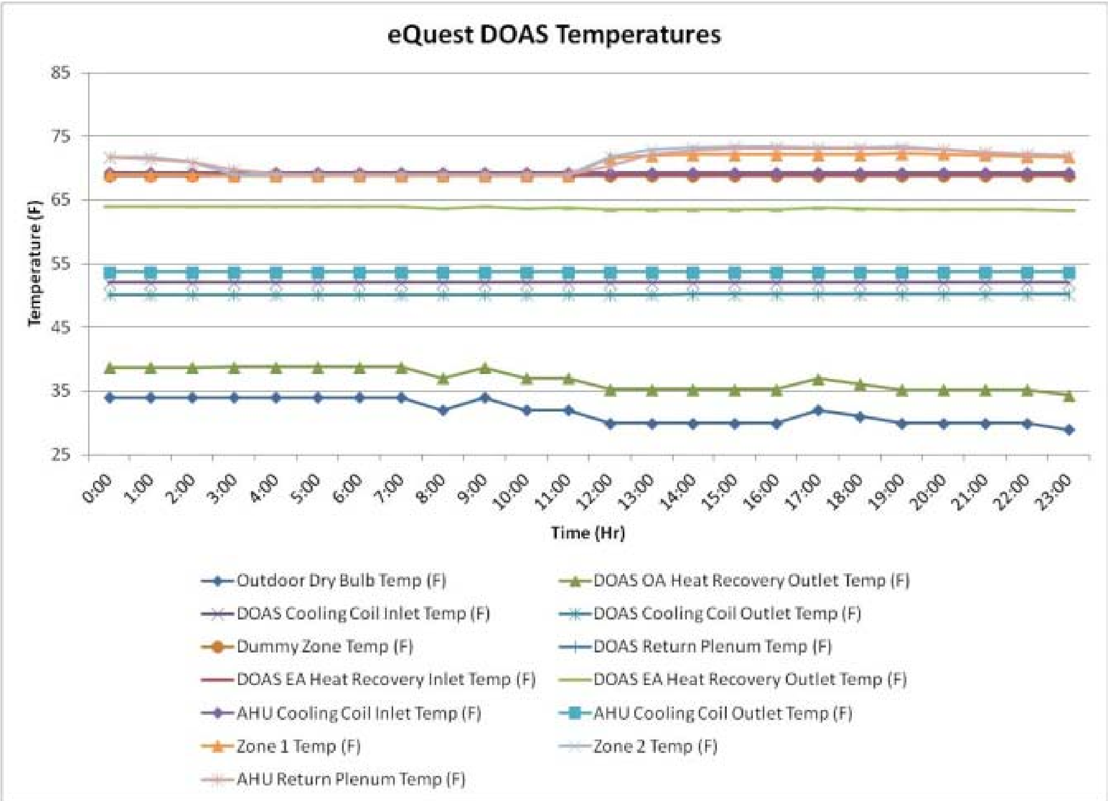


Figure 8: eQuest DOAS Temperatures

The data in Figure 8 shows that the outdoor air enters the DOAS between 29°F and 34°F (-1.6°C and 1.1°C) and is preheated to 34°F and 39°F (1.1°C and 3.9°C), and preheated to 50°F (10°C). The supply air is then provided to the zone attached to the DOAS, which is returned at 69°F (20.6°C). The air entering the the secondary AHU, it will not operate effectively as the air supplied to the secondary AHU is already conditioned to 55°F (12.8°C). A separate heat recovery calculation would have to be completed to determine the actual amount of heat recovered.

As stated in the introduction, it is often desired to supply chilled water at an elevated temperature to the

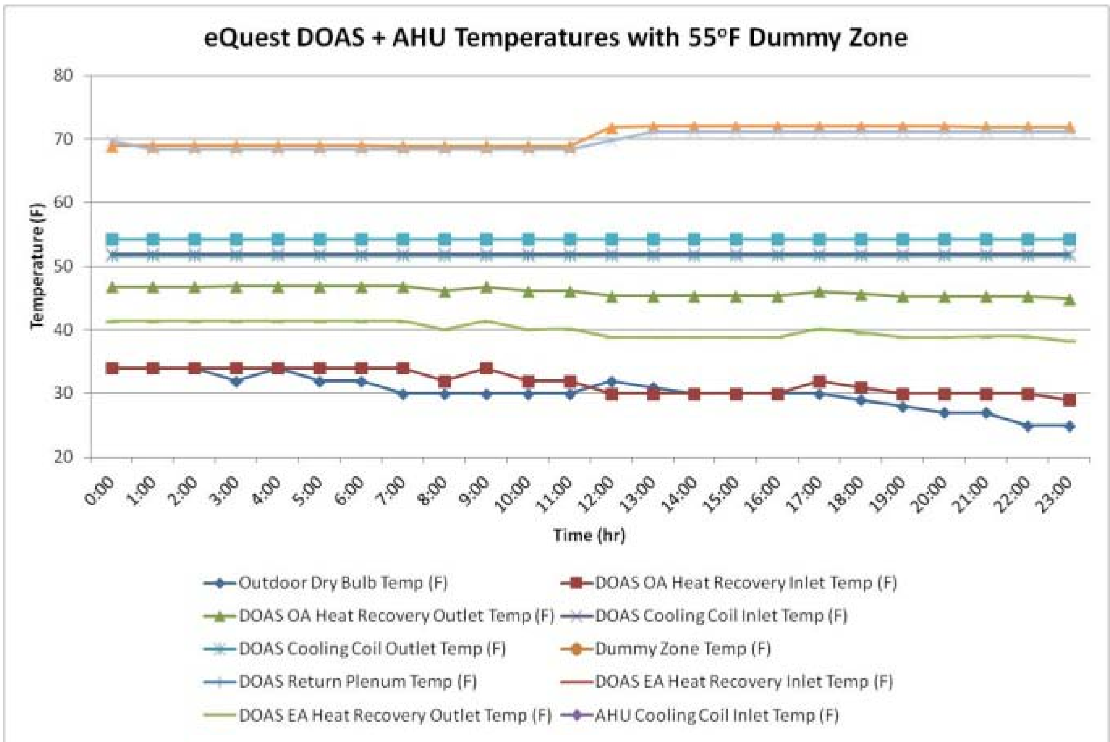


Figure 9: eQuest DOAS Temperatures with Dummy Zone.

ACB, however each system may be supplied by only one chilled water loop. Typically a cooling coil in the AHU is supplied by colder water than the ACB. The work around for this issue in eQuest is to create a DOAS, which preconditions the air with 42°F (5.5°C) chilled water, and provides 55°F (12.8°C) air to the IU system. If the main cooling coil is to provide warmer air, then the cooling coil will not operate and the remainder of the cooling will be accomplished by the induction unit. However, as stated in the previous paragraphs additional work arounds and difficulties arise from using a DOAS in eQuest.

A separate chilled water loop may be added by changing the zone level cooling loop to a secondary loop off the primary loop., however the secondary loop does not appear to work properly. The hourly reports show that the secondary loop temperature is the same as the primary loop temperature.

Issue #5: Issue five arises when a stand alone IU system is modeled and an elevated chilled water temperature is supplied to the system. eQuest sets a minimum temperature differential of 6°F (3.3°C) between the chilled water supply temperature and the main cooling coil leaving temperature. The purpose of this limit is unknown, but it does cause an error in the simulation. Furthermore, since eQuest uses the chilled water supply temperature to size air flow rate, a higher chilled water temperature causes very large air flow rates.

In conclusion, eQuest 3.64b can model chilled beams with a reasonable degree of accuracy for a final compliance model when all inputs are known, and the air handling units are constant volume, and are not tied to another air handling unit. Using eQuest for design assistance is fraught with difficulties and can very quickly lead to false conclusions.

Trane TRACE

Trane TRACE offers both ACB and passive chilled beam options. A four-pipe ACB system with a central cooling coil and heating coil can be modeled. The chilled beam coils are simulated as an auxilliary system coil and are activated in the event the central coils do not meet the space load. A maximum space humidity set point can be used to provide dehumidificationn at the central coil and limit condensation at the ACB. Trace has similar limitations to eQuest 3.64b including:

1. Single chilled beam capacity input for system with iterative zone primary airflow calculation necessary for sizing and ACB has a constant induction ratio.
2. There is limited humidity control at the zone level.

3. Air handling systems are rigid
    - Multiple terminal devices can't be assigned to a single system, ie. no combination of standard diffusers, chilled beams, fan coils, etc.
4. Multiple chilled water loops cannot be assigned to the ACB system.

Issue #1: The chilled beam capacity is defined as a Btu per lineal foot input for each system and is held constant no matter what the primary air flow is for a given time step. The primary airflow is specified at the zone input and needs to be iteratively determined along with the chilled beam coil capacity to make sure performance is consistent with manufacturer data, including the induction ratio as this cannot be directly defined.

Issue #2: As indicated in Issue #1, individual zone level iterations must be used to determine zone level primary air requirements. If zone level latent loads require primary air adjustments, these have to be made or Trace will override the temperature of the chilled water entering the chilled beam, effectively reducing its capacity in order to meet the maximum humidity set point. This can result in unmet zone loads.

Issue #3: Trace will vary air flow to the chilled beam if zone level minimum flow or ventilation rates are driving the air flow. Alternative system arrangements are limited as the ACB system cannot be combined with VAV terminals. Zone level heating units can be used in lieu of a four-pipe ACB however. A sample system flow diagram is shown in Figure 10.

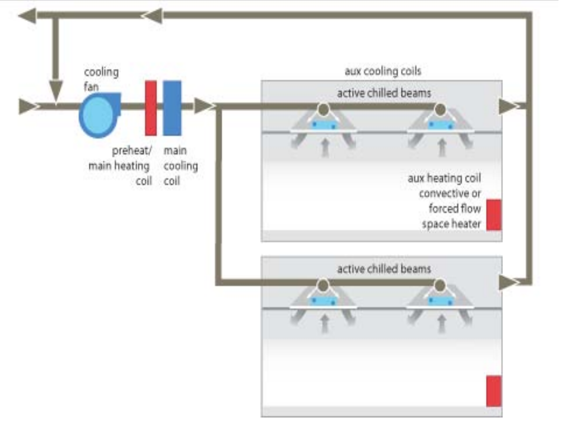


Figure 10: TRACE 700 ACB system

Issue #4: Multiple chilled water loops cannot be assigned to the same system in Trace, similar to eQuest, but Trace does default to maintaining an entering chilled water temperature to the ACB greater than the zone maximum dewpoint plus a safety factor. Chilled water flow is increased, but Trace has limited pump selections so it is unclear how exactly the pumping power is modified to account for this.

An additional issue is that Trace does not offer hourly reports at the zone level, which severely limits the ability to troubleshoot and ultimately, fully understand what the model is doing.

In conclusion, Trane TRACE provides limited flexibility, control, and data to validate ACB model results.

ENERGYPLUS

The chilled beam model used in EnergyPlus, which is referred to as cooled beam (AirTerminal:SingleDuct:ConstantVolume:CooledBeam), is derived from the cooled beam model that was originally implented in DOE-2.1E (DOE, 2011) . This is a quasi-empirical model that was originally developed based on coefficients for a particular manufacturer. The model is general enough that it may be tuned to other manufacturer's data.

The cooled beam model calculates the output of the chilled beam as a function of primary air flow rate, induction ratio, chilled water flow rate, room air temperature, chilled water temperature. The induction ratio can be modified to model either passive or active chilled beams.

EnergyPlus offers several advantages for modeling systems with ACB over the IU model currently used in eQuest. Unfortuately, many of the limitations of eQuest are currently still found in EnergyPlus, and EnergyPlus does not prove to be a robust tool for simulating all system types. EnergyPlus has the ability to model a Dedicated AHU for Chilled Beams (Figure 2) and AHU Central Air Handling System with Chilled Beam (Figure 3), but difficulties with handling complex air loops makes modeling the AHU DOAS Configuration (Figure 4) prohibitive for design purposes. EnergyPlus solves some of the issues found within eQuest including:

1. Cooled beam model varies induced air flow with chilled water to room air temperature difference.
2. Air handling systems allow slightly more flexibility, but have difficulty with handling secondary loops served from a single chiller.
    - A combination of terminal devices can be served from a single air handling system.
    - DOAS systems can be simulated in EnergyPlus, but the loop format for system equipment means that multiple AHUs cannot be ganged on a single heat recovery device. This

limits the possible configurations that can be accurately modeled.

  - Multiple chilled water loops may be assigned, but require a heat exchanger work around to mix loops at different temperatures served by a single chiller.

3. There is no limitation on the approach temperature of chilled water and coil leaving air temperature.
4. EnergyPlus allows for calibration with manufacturer provided performance data through the use of coefficients

An additional benefit of the the EnergyPlus model is generation of sizing information for chilled beams. The output of the sizing calculations include the quantity and length of beams, the required supply air flow rate, and the chilled water flow rate needed to meet the design load conditions. The sizing does have the limitation that the beam length increments can not be modified by the user.

A description of the limitations of EnergyPlus are listed below :

1. There is limited humidity control at the zone level.
2. Cooled beam systems are only constant volume.
3. Cooled beam is only capable of cooling.
4. Plant Loop Module and Air Loop Module have strict requirements for how individual HVAC components may be used. A loop is required to have a supply side and demand side with a chiller or AHU on the supply side and loads on the demand side. Each loop can only have a single set point (Two in the case of a primary/secondary chiled water loop). Mass transfer for fluid mediums is not allowed between loops.

Humidity control with ACBs in EnergyPlus is not explicitly provided for the cooled beam model. Work-arounds may be available to reset the chilled water temperature based on the ACB coil conditions, but a simple humdity control scheme would be a useful addition.

The cooled beam model is limited to constant volume, cooling-only systems at this time. This may be acceptable to some applications such as internal spaces that have significant internal gains or where exterior loads are relatively small.

Any system that requires a change-over and/or variable air volume systems cannot currently be modeled by the cooled beam model. A similar workaround to what is currently used in eQuest, using a constant volume single duct four-pipe induction unit (IU), is required to model a heating/cooling chilled beam system in EnergyPlus.

The IU model in eQuest determines the zone flow rate based solely on the primary air flow rate and the user-defined induction ratio, while the cooled beam model also includes the effects of the room air to chilled water supply temperature difference. This is included in the model as an additional source of induced air flow due to buoyancy effects. The additional input parameters in the cooled beam model allow for calibration with manufacturer provided performance data. While, calibration may be achieved by providing appropriate model coefficients, it is unknown how reasonable it is to calibrate these models with actual experimental data. The multi-dimensional nature of the performance data will likely make an individual product difficult to fit the current EnergyPlus model to the data.

The primary limitation of modeling chilled beams in EnergyPlus is the simplification of the system and plant models into discrete loops. EnergyPlus is developed in this manner in order to eliminate the need for additional iterations, that are required by simultaneous solvers when the system of equations becomes large. This improves the speed of the simulation and simplifies the numerics required for convergence. The trade-off is that EnergyPlus can only accurately model HVAC systems that are in discrete systems or plant loops, and it has difficulty with the complex multi-temperature air and chilled water loops that are commonly implemented in institutional HVAC infrastructure. These complex facilities (e.g. laboratories and healthcare) are currently where ACB are actively being proposed as a viable energy conservation measure (ECM). 100% effective heat exchanger objects may be used to bridge various loops, but implemention of these schemes must be accomplished with extreme care to insure proper operation of both loops.

IES-VE 4.6.0.7

Modeling ACB in IES-VE is possible but not completely without challenges. The air-side system in IES-VE is well developed, where the user can choose from several predefined so called “prototype” (template) HVAC systems within the Apache-HVAC module. IES-VE allows the user to select from one of the two predefined ACB systems such as a 2-pipe (Figure 11) or 4-pipe (Figure 12) system or a custom system can be assembled using the multi-zone HVAC network.

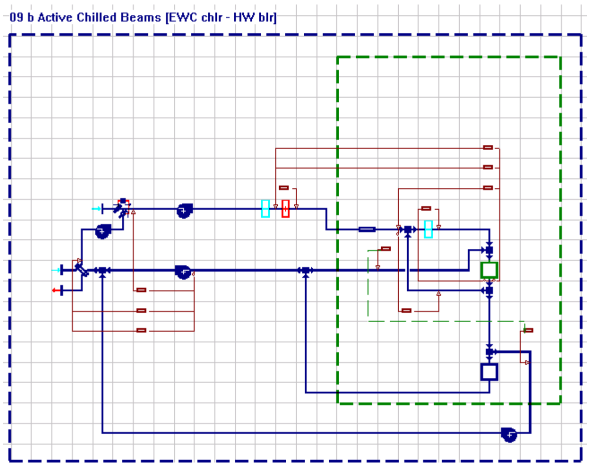


Figure 11: IES-VE 2-pipe ACB system

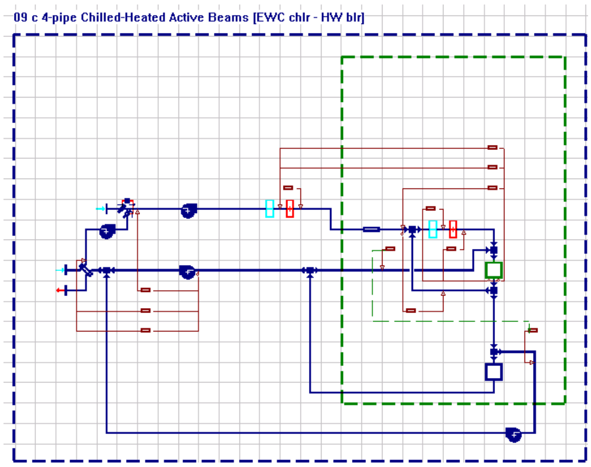


Figure 12: IES-VE 4-pipe ACB system

The ACB in IES-VE is modelled as a Fan-Coil Unit (FCU) conected to a DOAS system. The DOAS ensures proper amounts of conditioned primary air whereas the recirculation branch (typical for FCUs) provides induced flow. The ACB models accepts variable airflow, and uses a constant induction ratio to vary the amount of induced air flow via a proportional controller. Zone level induction ratio values may be added if desired.

Furthermore, IES-VE offers a fair bit of flexibility of the air side flow diagram, but care must be taken when mixing ACB and more standard VAV systems.

The plant side of the software is sufficient to model ACB with separate chilled water loops feeding the cooling coil and the ACB. In this version of IES, up to ten chilled water loops, with an primary/secondary arrangement, can be used to feed chilled water to ACB. Furthermore, humidity control can be added to provide a chilled water reset to prevent condensation. It should be noted that the water-side plant modeling of IES-VE is limited to relatively simple chiller and boiler systems, and is not as well developed as the air-side portion.

Accurate modeling of ACB in IES-VE is feasible, however some challenges persist including:

1. Constant induction ratio
2. Manual system sizing

Issue #1: As stated, the induction ratio in IES-VE can vary amongst zones but not within the zone itself. This means that IES-VE is not able to capture changes in induction when other than a design flow is used at the beam but rather it operates using a constant induction ratio. This discrepancy will cause some performance issues as induction ratio is not constant when airflow varies.

Issue #2: Sizing of an ACB system is done outside of the Apache HVAC module. Once the multi-zone network has been layed out, IES-VE will export zone/system data into a spreadsheet file. This is then used to further modify/edit zone/system inputs for equipment sizing. Also oversizing factors and ASHRAE 62.1 requirements can be added in the spreadsheet at this point. In order to size the ACB, the spreadsheet is used to enter induction ratio and adjust the primary airflow min. and max. for the zone(s) if a variable system is modeled. Once done editing, data from the spreadsheet is imported back into IES-VE. This works well for typical ASHRAE 90.1 systems, but is somewhat cumbersome for other custom systems. The cause of this is that IES-VE does not autosize non-standard systems very well. Therefore, as the building design changes or different features are added and removed, the spreadsheet may need to be edited again. In essence, the chilled beam values must be hard coded and if the loads and air flow rates change substantially, the model may no longer be accurate.

Thus, complexity is added for buildings with large numer of zones and especially with mixed use (i.e., primary air supplied from DOAS for both VAV and ACB).

In conclussion, IES-VE is very powerful on the air-side, but can be cumbersome during the design process where loads and design are changing frequently. It has some limitations but provides the most comprehensive means of modeling ACB systems at this time.

TRNSYS 17

A proprietary ACB TRNSYS component has been developed that allows for significant flexibility in the model of various ACB. The ACB component is supplied with:

- primary air temperature and flow,

- chilled water supply temperature and flow, and
- room air temperature and relative humidity.

The ACB component has two additional inputs that define the ACB; an induction ratio and a bypass fraction. The induction ratio is a variable that can be set based on user preferences and influenced by the supplied airflow rate.

Based on the air flow rate calculated from a separate VAV controller and the induction ratio, a quantity of room air is induced into the ACB component. A portion of the induced air is bypassed around the coil based on the bypass fraction. The non-bypassed part of the secondary air stream goes past the coils and comes out saturated at the coil average water temperature. The rest of the secondary stream bypasses the coil entirely and the two streams are remixed, coming out above the dewpoint. The remixed secondary and primary air streams are then remixed and are input into the zone. Furthermore, the radiant portions of the heat transfer is also taken into account. Therefore, as the zone temperature increases, the radiant output of the beam also increases.

A simple ACB model is shown in Figure 13 with a zone varying temperature schedule to mimic the temperature rise a space might see over the course of a day.

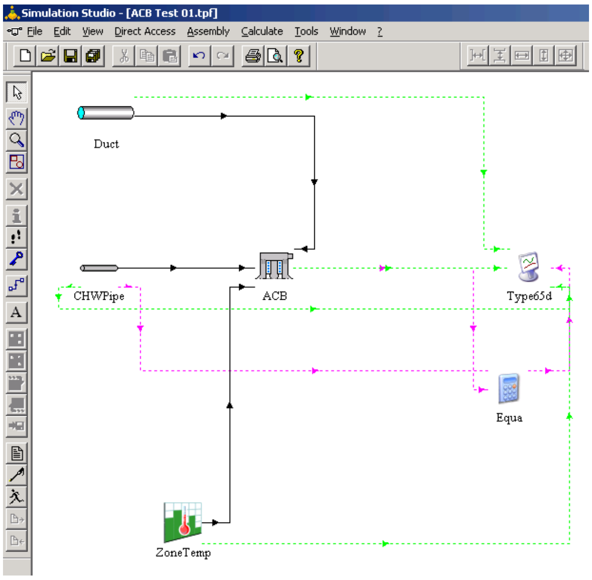


Figure 13: TRNSYS ACB Model

Figure 14 shows the temperatures in degrees Celcius for each flow stream, and how the system chilled beam reacts to a rising temperature in the space.

The blue (top) line shows the zone temperature over the course of a 24 hour period. The red (middle) line shows a constant primary air temperature of 55°F (12.8°C). Similarly, the purple line (bottom) provides a shows a constant chilled water supply temperature of 58°F (14.4°C). The orange line (4th from top) shows the chilled water return temperature, which varies as the load in the room changes. A variable speed drive on the pump, would be able to maintain a constant chilled wate return temperature, but in this case displaying reaction to the zone temperature increase was desired. Finally, the green line (2nd from the top), shows the temperature of the air being supplied to the zone, which varies with the zone load. Again, a controller would either provide more primary or chilled water to maintain a zone supply air temperature, but again this was not modeled to show the functionality of the model.

The TRNSYS ACB model provides the most detail of any ACB model surveyed in this document, however it comes with two key limitations. First, as stated in the manufacturers data section, a performance map approach would be best for modeling chilled beams rather than a simplified approach of tweaking induction ratio and bypass fraction. The performance map could be created once for each particular type of beam and could be reused for a variety of different circumstances. This would eliminate some of the iterative efforts with modeling in TRNSYS, and will be included in the next version of the model.

The second issue is more complex in that each beam must be modeled individually. There is no means of applying beams to several zones all at once such as the other software previously described. Each beam must be added one at a time and connected to the appropriate zone model. This becomes time and cost prohibitive if numerous zones with chilled beams are desired.

It should be noted that a common misunderstanding among TRNSYS users is that TRNSYS cannot model VAV systems. This is not the case, however there is no canned VAV control component or VAV AHU. A custom controller must be written that uses the loads and ventilation requirements of each space to determine the proper flow rate. This is somewhat cumbersome, but feasible.

In conclusion, the TRNSYS ACB model is very useful for detailed design needs and provides nearly unlimited flexibility for controls strategies. This is attractive when designing and/or optimizing one or two spaces. However as the number of zones increases, or an entire building model is necessary, the complexity of keeping track of links within the model increases rapidly.

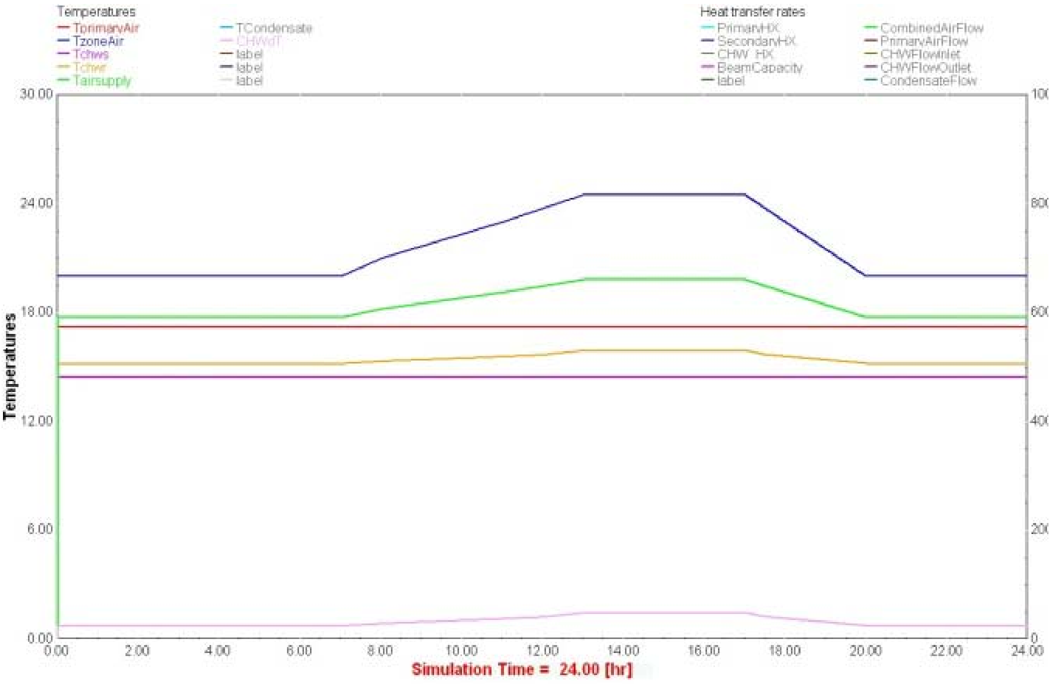


Figure 14: TRNSYS ACB Temperature vs. Time.

RESULTS

Table 1 compiles results for each piece of software focusing on the features to model a modern HVAC system with ACB.

Chilled Beam Modeling Results					
Criteria \ Software	eQuest (3.64b)	Trane TRACE	EnergyPlus (v7)	IES-VE	TRNSYS
System Induction Ratio	YES	YES	NO	NO	NO
Zone Induction Ratio	NO	NO	YES	YES	YES
Variable Induction Ratio	NO	NO	NO	NO	Yes
CAV	YES	YES	YES	YES	YES
VAV	NO	NO	NO	YES	YES
Multiple CHW Loops	NO	NO	MIXED	YES	YES
Humidity Control	MIXED	MIXED	NO	YES	YES
Flexible HVAC Configuration	NO	NO	MIXED	YES	YES
Intuitiveness	MIXED	MIXED	NO	NO	NO
Compliance Model	YES	YES	YES	YES	MIXED
Design Assistance	NO	NO	MIXED	MIXED	YES
Modeling Time	LOW	LOW	MID	MID	HGH
Software Cost	FREE	LOW	FREE	HIGH	MID
Simulation Time	FAST	FAST	MID	SLOW	SLOW

Table 1: Chilled Beam Modeling Results

Each software has its pros and cons beyond it's ability to model ACB, and must be selected carefully before proceeding as accuracy must be balanced with time and budget constraints.

Most of the rows in Table 1 are filled in based on information from the previous sections. Additional qualitative results are included in Table 1 that are useful for energy modelers and software developers. Intuitiveness and modeling time are based on the assessments from more than a dozen energy modelers at Affiliated Engineers, Inc. While this is not a statistically significant data set, this type of feedback is important for software developers in order to optimize their tools for broader implementation. Additional feedback should be provided.

Simulation time refers to the speed at which models are run. While this is very dependent on model size, and the computer on which the models are run; certain software do run noticebly slower than others. To assist in the design process, the faster the run times, the better.

Compliance modeling refers to models that provide sufficient accuracy for a federal, state or certification (GreenGlobes, LEED, etc.) compliance model. All the tools meet this requirement, however TRNSYS has some limitations as there are no canned reports that reviewers are familiar with. All outputs from TRNSYS are in a modifiable text file, which may lack credibility with reviewers and code authorities.

Design assistance modeling refers to models that provide sufficient support and detail in order to inform actual building designs. For example, an eQuest model does not provide a reliable cooling load split between the main cooling coil and the ACB. On the other hand, the TRNSYS model provides sufficient data, which allows a designer to trust the results in order to optimize the design.

DISCUSSION

The overall goal for any modeling software is to improve designs through relatively low cost mathematical models rather than through expensive experiments and mockups. This is especially true for building models where custom solutions are the norm as climate, geometry, and user behaviors vary greatly from project to project.

In order for practicing architects and engineers to effectively utilize the models, accuracy and speed are critical. In today's climate of tight budgets and short project delivery times, energy models often fall short of expectations. More accurate models can lead to right sizing system, thus reducing first costs, operating costs, and potentially expensive retrofits. However, justifying the upfront design costs and time can be challenging.

In order to trust these models and avoid the cost of experiments and mockups, the software must be improved and validated to a greater extent, which may be addressed by a new research topic from ASHRAE titled, "Testing and Modeling Energy Performance of Active Chilled Beam Systems" (Bauman, Lee, Nelson 2011).

Furthermore, a complete software package needs to be created that can model simpler geometries and systems quickly, but allow for more complex geometries and systems if desired. The primary driver for this is the lack of time for training. Today, a VAV system with a relatively simple façade is what comprises the standard building model. This can be handled accurately and quickly in many simple software such as eQuest or Trane TRACE. Furthermore, most baseline models based on ASHRAE 90.1 for LEED and State compliance are VAV systems. Therefore, at least 50% of all models will be VAV or CAV systems. As such most energy modelers must be trained to model these types of systems quickly to maximize time spent on assisting the design rather than on compliance modeling.

If a modeler needs to use a different piece of software to model a non-standard HVAC system or plant, which they are less familiar with, then the amount of time spent modeling increases significantly. Essentially, it is impossible for one person to master the dozens of software needed to accurately complete an energy model today. That's why eQuest and Trane TRACE are used to model chilled beams so frequently, because the user base has a relatively good understanding of the software even if it is frequently misapplied.

Software developers need to investigate what works, and what doesn't in other software, and integrate similar concepts into their software. It is understood that speed, accuracy, and flexibility often contradict one another in energy models. However a balance must be struck if energy modeling is to advance beyond VAV systems, and allow for more advanced techniques that are more common in academia to make their way into the built environment.

CONCLUSION

The performance modeling software available today have multiple issues with modeling active chilled beams whether it be accuracy, ease of use, and/or cost. Strides must be made in order for building designers to reliably use a software to inform design quickly and accurately.

RECOMMENDED FUTURE WORK

The future work must proceed on two fronts, which include the development of better tools, and the generation of performance data to validate tools.

Metering and performance testing of real buildings is becoming more common. Data from buildings with chilled beam installations must be made available to the modeling community in order to provide realism to the models as relatively few rules of thumb exist for performance comparisons.

Furthermore, a continued dialogue between the design and modeling community needs to take place that informs tool design. Frequently it appears that the software tool developers receive little in the way of feedback from the end-users of their products. This lack of feedback needs to be addressed as this would provide direction for research and development funds.

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NOMENCLATURE

ACB = Active Chilled Beam

AHU = Air Handling Unit

CAV = Constant Air Volume

DOAS = Dedicated Outdoor Air System

HVAC = Heating, Ventilation, and Air-Conditioning

IU = Induction Unit

VAV = Variable Air Volume

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