A Method for Simulating Heat Recovery Systems Using AirModel in Implementations of the ASHRAE Simplified Energy Analysis Procedure

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Abstract

A method for simulating heat recovery systems using AirModel in implementations of the ASHRAE simplified energy analysis procedure was developed in this paper. AirModel, a simulation tool used to simulate the energy consumption of building heating, ventilating, and air-conditioning (HVAC) systems, was developed by the Energy Systems Laboratory (ESL) at Texas A&M University (TAMU) in the 1990's. This program is capable of simulating single duct reheat systems and dual duct systems with economizer cycles. However, in certain buildings, energy savings techniques such as heat recovery systems are implemented but AirModel does not have a specific input to simulate this system. Presented in this paper is a method to simulate a heat recovery system using AirModel.

With AirModel, the heat recovery could be simulated for pre-heating and pre-cooling of outside air at all outside air temperatures or at low and/or high outside air temperatures. This allows one to evaluate and simulate a heat recovery system in more detail and determine an optimal operating schedule. To simulate an HVAC system with a sensible heat recovery system, the return air ratio was adjusted in AirModel. The adjusted return air ratio was calculated by using the heat recovery parameters, weather data, and room temperatures. The heat recovery system was then modeled as a heat exchanger to verify the return air ratio. In this comparison, the recovered energy from the return air was equalized with the heat transfer of the heat exchanger model. An example of this methodology was used to simulate the HVAC system with a heat recovery system for the Biophysics and Biochemistry building on the TAMU campus.

Introduction

AirModel is a simulation tool developed by the Energy Systems Laboratory (ESL) at Texas A&M University in the 1990's. It uses the bin method simplified energy analysis to calculate energy consumptions. AirModel is primarily used to simulate building heating and cooling consumption using hourly, daily, monthly or Bin weather data. AirModel has the capability to simulate building electricity consumption as well as central plant consumption. Systems which could be simulated in this program include dual duct with outside air pretreat, dual duct with mixed air pretreat, single duct with reheat and outside air pretreat, single duct with reheat and mixed air pretreat, single duct with heating and then cooling and single duct with cooling and then heating. For simulation purposes schedules can be chosen to "turn off" certain parts of the systems if required, such as the cold deck, hot deck, and pretreat decks. Inputs for AirModel include building data, internal load data, and HVAC systems and equipment data as well as climatic data. The building data includes occupancy, envelope, and floor, wall and window areas. The solar load on the building is manually calculated and included as a building load. The internal load input is a manual calculation estimating the lighting, people, and equipment loads. Hourly fractions of the maximum internal load can be specified as well. To prepare the input files for the HVAC systems and equipment, separate subsystems are utilized. Thus, systems with similar components and operations can be grouped in one subsystem.

Duty cycles for the subsystems can be specified in the AirModel.

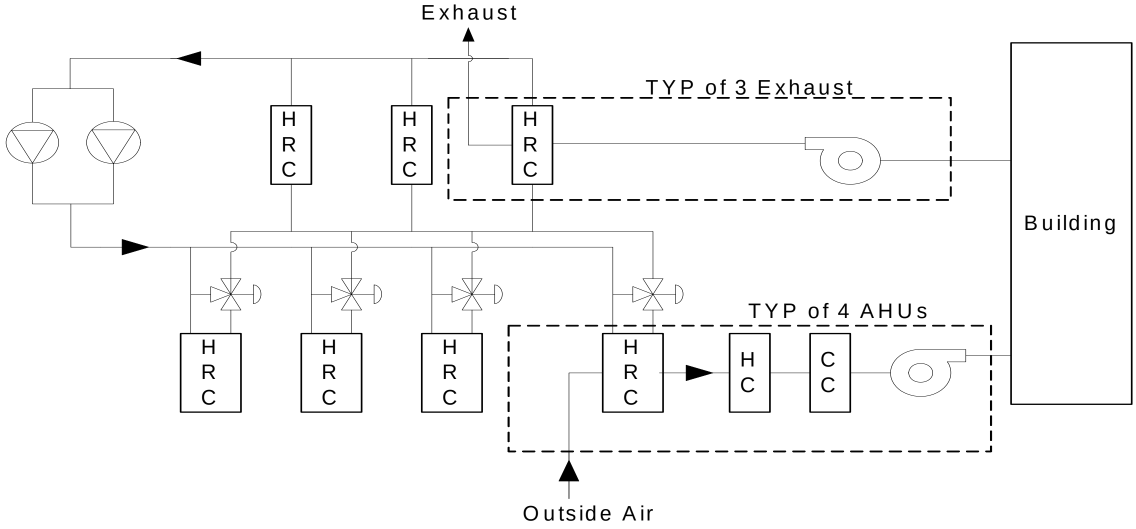

Figure 1: Schematic of the heat recovery system in Bio-Bio Building

With the climatic data and building internal, envelope, and operational data, the building loads are calculated and then the building HVAC system and equipment energy requirements are calculated. If plant data was included in the simulation inputs, the plant system energy requirements are further calculated as well. The output files for AirModel are in the form of text files which need to be opened using Microsoft Excel and desired charts and graphs need to be manually created. Currently, a new version of AirModel is being developed at ESL which is Microsoft Windows compatible. This use of windows allows inputs be easily specified and the charts and graphs are automatically generated when the systems are simulated. The outputs are listed as well in a text file for user review of data.

In certain buildings, energy savings techniques such as heat recovery systems are implemented but AirModel does not have a specific input to simulate this system. This paper presents a method to simulate a heat recovery system using AirModel and an example of its use. This method can be used to simulate the building heat recovery from the heat exchange between exhaust air and fresh air. The heat recovery system could be air to air heat exchanger, heat wheel, or glycol medium heat recovery system. The example involves a glycol medium heat recovery system which is illustrated in Figure 1, and is located in the penthouse of the Biophysics-Biochemistry (Bio-Bio) building on TAMU campus. This system has two glycol pumps, four air to water heat exchangers located in the AHUs to pre-treat the outside air, and three air to water heat exchangers located in the building exhaust side to recover the sensible cooling or heating energy.

Other Simulation Tools and Their Heat Recovery Systems

Popular building energy consumption simulation tools include BLAST, DOE-2, and EnergyPlus. BLAST was developed in the 1970's by the US Army Construction Engineering Research Laboratory. This program uses a heat balance approach to determine energy consumption. BLAST simulates basic HVAC systems and does not have the capability to simulate a heat recovery system.

DOE-2 was developed for the U.S. Department of Energy in 1980 and has been updated in subsequent years. This simulation program is capable of performing space load calculations as well as simulating building and power plant energy consumption. DOE-2 is a powerful program which uses a room-weighting factor approach to determine building loads and energy consumption. This program is widely used in the United States and is used by consulting firms and government agencies as well as in universities for research and teaching purposes. This program has the capability of simulating a heat recovery system, however, there are limitations. DOE-2 can only simulate a heat recovery system when the HVAC system is in the heating mode. This is good for northern climates where a heat recovery system is utilized primarily at cold outside air temperatures. In southern climates, a heat recovery system is utilized at cold outside air temperature conditions as well as hot outside air temperature conditions and thus needs to be simulated in the heating and cooling modes.

EnergyPlus was developed by Lawrence Berkley National Laboratories for the U.S. Department of Energy in 1996 and released in 2001. EnergyPlus is built off of the features and capabilities of DOE-2 as well as BLAST. This program also includes the capabilities of sub-hourly time steps and modular systems. EnergyPlus has more capabilities for simulating HVAC systems as well as plant systems, including those equipped with heat recovery systems. There are two types of heat recovery system simulations in this program for building exhaust air energy recovery. The first one is for air to air heat exchanger (flat plate and rotary heat exchanger). The second system is for stand alone air ventilator. However, none of above two heat recovery models can be used directly to simulate the heat recovery system in Figure 1, which has glycol coils to pre-treat the air for AHUs.

There are multiple other simulation tools developed by private institutes and persons for use but none are as popular as the above mentioned programs and have not been considered for this paper.

AirModel Heat Recovery Simulation Methodology

Since AirModel does not have a specific function or input to simulate an HVAC system equipped with a heat recovery system, a method was derived. This will allow the user to estimate potential savings of a heat recovery system before the system is installed or commissioned. It is beneficial to simulate a heat recovery system to determine its actual potential savings. If an HVAC system is a variable air volume (VAV) system, the maximum design savings attributed to a heat recovery system would not be seen at all times due to the system operating at part load most of the time. Either a system load factor needs to be used to quickly calculate the estimated savings or a simulation tool capable of simulating a VAV system can to be used to accurately estimate the potential savings.

The method derived to simulate a heat recovery system for use with AirModel involved determining the capacity of the existing or designed heat recovery system at an extreme high and low outside air temperature and then calculating the return air flowrate needed to equal the capacity of the system at these two temperatures. By allowing return air or an increase in return air to mix with the incoming outside air in the simulation, the transfer of energy between the exhaust air and incoming outside air can be simulated. AirModel has a function where the user defines the amount of outside air and supply air by the HVAC system, thus the amount of return air is indirectly specified by the user and calculated by AirModel.

With AirModel, the total supply air could be allowed to vary to simulate a variable air volume system. The amount of outside air could be allowed to vary depending on the specified outside air control method. Once AirModel determines the required supply air and outside air, it could then calculate the amount of return air.

A heat recovery system basically recycles waste sensible heat or cooling capacity from the exhaust air stream and utilizes it to pretreat the incoming outside air. This heat transfer between the two air streams is via an air-to-air or air-to-water heat exchanger. In effect, for simulation purposes, return air or an increase in return air (if the system has return air) from the exhaust stream could be mixed with the incoming outside air to simulate the process of pretreating the outside air. In order to determine the amount of return air required to simulate a heat recovery system, the capacity of the existing or specified heat recovery system needs to be known. By knowing the capacity of the heat exchanger, the capacity itself can be simulated and not a specific type of heat recovery system. Thus, a heat exchanger can be of multiple types such as an air-to-air or air-to-water heat exchanger. Typically, a heat recovery system has a design condition for two specified outside air temperatures, one for an extremely cold outside air temperature and one for an extremely hot outside air temperature. At these two design outside air temperatures, a heat transfer rate should be specified as well as the treated incoming air temperature once it passes through the heat recovery system. With this data known as well as the return air temperature known, the required return air ratio can be determined. The return air ratio (RAR) is the return air flowrate divided by the supply air flowrate.

For the calculation of the return air ratio (RAR), the following equation is used:

$$RAR = \frac{cfm_{RA}}{cfm_{SA}} = \frac{Q_{HR}}{1.08 * cfm_{SA}\left|(T_{OA-}T_{RA})\right|}$$

Where cfm_{RA} is return air flowrate and cfm_{SA} is supply air flowrate, in cubic feet per minute. Q_{HR} is heat recovery design cooling/heating capacity with units of Btu/hr. T_{OA} is a design cooling/heating outside air temperature, °F. T_{RA} is a return/exhaust air temperature, °F. It is assumed that the density and specific heat of air are constant at 0.075 lbm/ft^3 and 0.24 Btu/lbm-°F, respectively. With these two constants and a conversion from minutes to hours, a constant of 1.08 is derived with the units of Btu-min/ft^3-hr-°F. This equation is for use with a cross flow type heat exchanger where the leaving air temperature of one air stream approaches that of the other stream. This equation is to find the outside air ratio in the winter when the system is in heating mode and for the summer when the system is in the cooling mode. Due to the heat recovery system characteristics, there will be two RARs, one for the cooling mode and one for the heating mode. Once the RAR is calculated, the outside air ratio (OAR) must be calculated by subtracting the RAR from the number one, since AirModel has an input for OAR rather than RAR. Since AirModel accepts only one input for the OAR, an average of these two ratios from the heating and cooling modes needs to be calculated.

In order to simulate a building with a heat recovery system and determine the savings attributed to the heat recovery system, the building must firs be simulated without a heat recovery system. The difference between the two simulation energy consumptions is the potential savings attributed to the existing or potential heat recovery system for that building.

In most cases, a heat recovery system is present on an HVAC system where the outside air makes up approximately 80% to 100% of the total supply air. As detailed earlier, in order to simulate a heat recovery system in Airmodel, a required RAR must be determined to model the sensible heat transfer between the exhaust and incoming outside air. An OAR is then calculated and put into the simulation input file. If the simulation was ran with only this change to the OAR, the heat recovery system would be simulated as if were always operating. However, in some instances, it is not favorable to run the heat recovery system at all outside air temperatures since the cost to run the system out weighs the savings realized by the system. In order to simulate the heat recovery system with an on/off period the following procedure is followed. This procedure allows the heat recovery system to run at low outside air temperatures only, high outside air temperatures only, or run at low and high outside air temperatures and remain off at moderate outside air temperatures. In order to turn the heat recovery system "off" in AirModel, the economizer cycle input in AirModel is utilized. By turning the economizer cycle on, the heat recovery OAR is overridden to use the economizer cycle specified OAR fraction. The economizer OAR fraction needs to be the same as the OAR for the simulation without a heat recovery system. Thus, when the economizer is on, the heat recovery system is "off" since the economizer OAR is the same as if there is no heat recovery system being utilized. The economizer cycle in AirModel can be specified to turn on for a given outside air temperature range. If the economizer cycle is specified on when the outside air temperature is 70°F or lower, then the heat recovery system is simulated when the outside air temperature is above 70°F. If the economizer cycle is specified on when outside air temperatures are greater than 50°F, then the heat recovery system is simulated when outside air temperatures are less than 50°F. If the economizer cycle is specified on between the outside air temperatures of 55°F and 75°F, then the heat recovery system is "on" when the outside air temperature is lower than 55°F and when the outside air temperature is greater than 75°F.

Example of using this Method

The method described to simulate a heat recovery system using AirModel was used when simulating the Biophysics-Biochemistry building on the TAMU's Main Campus. The Biophysics-

Biochemistry building is a four-story building with a total conditioned area of 150,000 ft^2. Located on the West Campus of Texas A&M, this building was constructed in 1990.

The method described to simulate a heat recovery system using AirModel was used when simulating the Biophysics-Biochemistry building on the Texas A&M University's Main Campus. The Biophysics-Biochemistry building is a four-story building with a total conditioned area of 150,000 ft^2. Located on the West Campus of Texas A&M, this building was constructed in 1990. The first floor consists of offices, a bookstore, a copy center, two large lecture rooms, the Ag Cafe dining area and kitchen, and student computer labs. The remaining three floors are primarily laboratories. Each of these floors consist of 9 to 12 laboratory suites, where each suite consists of two laboratory rooms and a holding/storage area in the space between the two laboratories. There are environmental chambers and offices located on these floors. Above the fourth floor is the penthouse which houses all of the Air Handling Units (AHUs), except one, which is located on the first floor. The Biophysics-Biochemistry building is served by 10 AHUs. Four of these units serve approximately three-quarters of the building. These are AHU's L1, L2, L3, and L4. These units serve all of the laboratories on the 2nd, 3rd, and 4th floors. Each unit serves the same relative area for each floor via a common chase in the center of the building. Each supply duct, as well as other plumbing, utilizes this chase to run from the penthouse to the lower floors. The remaining AHUs are AHU B, C, S, D, O, and SG which serve the bookstore, copy center, seminar rooms, dining area, first floor offices, and the switchgear room in the penthouse, respectively.

The AHUs which serve the three laboratory floors are all 100% outside air units. Due to the large amounts of outside air to be conditioned, there is a heat recovery system for these units.

Air-Water Exchanger		Airflow Rate (cfm)	Winter MBH @72 EAT	Summer MBH @78 EAT	Glycol GPM	Remarks
Exhaust Side	**HRC-1**	40,700	956	385	208	
	HRC-2	44,600	1,054	425	215	
	HRC-2	45,600	1,087	435	230	
AHU Side	**AHU/L-1**	44,500	939	374	185	
	AHU/L-2	45,000	940	376	191	
	AHU/L-3	44,500	939	374	185	
	AHU/L-4	11,760	229	92	96	

Table 1: the Performance of the Heat Recovery in Bio-Bio Building on ATMU Campus.

The heat recovery system is a glycol system with three air to water heat exchangers located in the common exhaust ducts for these floors and four air to water heat exchanger located in the 4 AHUs to pre-treat the outside air as shown in figure 1. The performance of this heat recovery system is shown in Table 1. Each AHU then has a preheat coil and a cooling coil following the heat recovery coil. A pre-heat coil is needed because the heat recovery coil has insufficient heating capacity at very low outside air temperatures. AHUs L1, L2, and L3 are all equipped with Variable Frequency Drives

Bio-Bio Building Annual Energy Consumption & Savings		CHW (MMBtu)	HW (MMBtu)	CHW ($)	HW ($)	CHW&HW ($)
Calibrated Simulation	**Consumption**	26067	9268	$294,296	$73,681	$367,977
HR Simulation	**Consumption**	23619	8575	$266,659	$68,171	$334,830
	Savings	2448	693	$27,638	$5,509	$33,147
	% Savings	9.4	7.5	9.4	7.5	9.0

Table 2: Annual Simulated Energy Consumption and Annual Potential Savings.

(VFDs) and AHU L4 is a constant volume unit. All four units are controlled through the Energy Management Control System (EMCS). Since the units utilizing the heat recovery system are equipped with VFDs, the AHU's do not operate at full capacity all the time. Thus the energy savings from heat recovery system can not be calculated directly from the system cooling/heating capacity. So, the heat recovery system was simulated using AirModel to determine possible savings. Due to certain conditions, the heat recovery system in this building has not been operating for several years. During the building commissioning process, it was desirable to determine if the heat recovery system should be brought back on line. Due to this and other HVAC scheduling recommendations, the building was simulated for possible savings.

Prior to simulating the building with a heat recovery system a calibrated simulation based on existing building chilled and hot water energy consumption was generated. Once a calibrated simulation was generated, a proposed heat recovery operation schedule was determined. It was determined that the heat recovery savings could be seen when the outside air temperature is below 55°F and above 78°F. Above 78°F, the heat recovery system would operate at full capacity with the control valves fully open. When the temperature is below 55°F, the heat recovery system control valves should modulate to maintain a pre-treat temperature of 58°F. At low outside air temperatures, the heat recovery coil does not have the capacity to pre-treat the air to the desired temperature thus the pre-heat control valve will begin to modulate and maintain the pre-treat set point of 55°F when the heat recovery coil is not sufficient. When the outside air temperature is between 55°F and 78°F, the savings attributed to the heat recovery system do not outweigh the actual cost of running the heat recovery system. This was determined by calculating the costs to operate the glycol pumps of the heat recovery system and comparing this to the simulated savings of running the heat recovery system at all outside air temperatures.

Recovery	Q_{HR} (MMBtu/hr)	T_{OA} (°F)	T_{RA} (°F)	RAR
Cooling Energy	1.247	96	75	37%
Heating Energy	3.047	25	72	41%

With a heat recovery operating schedule given in the building drawings, the required return air ratio was determined. Table 3 shows the design data for the heat recovery system in the Biophysics-Biochemistry building. The RAR for the cooling mode is 37% and 41% for the heating mode. The average RAR is 39%. Once the inputs for the heat recovery system were know, the calibrated simulation input file

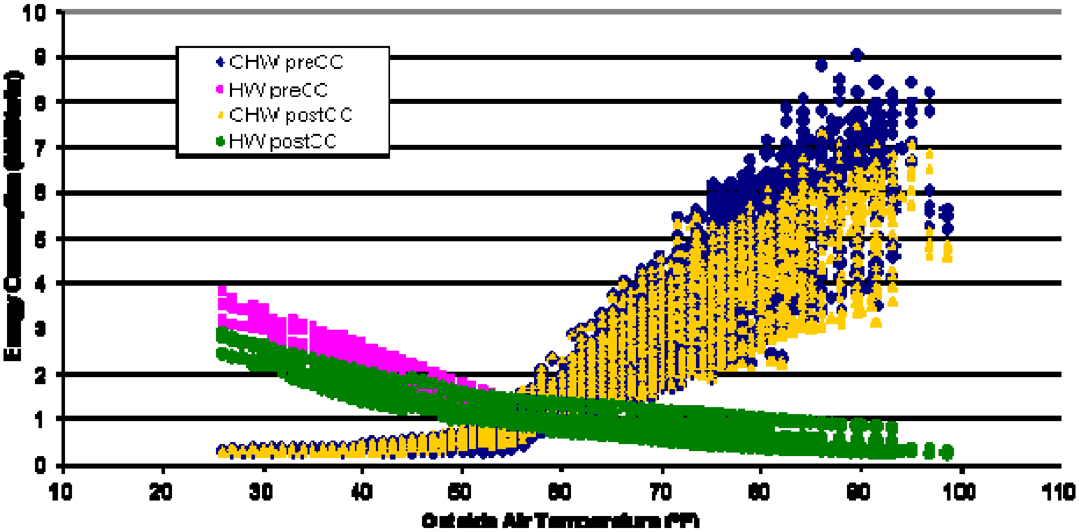

Figure 2: Bio-Bio building calibrated energy consumption simulation (preCC) and simulated energy consumption with a heat recovery implemented (post CC).

was modified and the building with the heat recovery system was simulated. Figure 2 shows the calibrated simulation energy consumption for the Biophysics-Biochemistry building versus the simulation including the heat recovery system. As shown in Table 2, the simulated cooling energy savings from implementing the heat recovery system were 2448 MMBtu/yr ($27,638/year at $11.29/MMBtu) for chilled water consumption and 693 MMBtu/yr ($5,509/year at $7.95/MMBtu) for hot water consumption, a 9.4% and 7.5% savings, respectively. The weighted average for these two savings is 9.0%. The total cooling and heating savings are $33,147 per year. The cost to operate the heat recovery system is approximately $2,870 per year, which was derived from the operation of the heat recovery pumps during the hours in which the heat recovery system operates. Using local Bin weather data, the average number of hours per year at specific outside air temperatures was used to determine how many hours the heat recovery system would operate on average per year.

Conclusion

A method for simulating heat recovery systems using AirModel in implementations of the ASHRAE simplified energy analysis procedure was developed in this paper. In the example, a heat recovery system was simulated through this method and its results are acceptable. In order to compare simulation results, a years worth of hourly data needs to be measured for further investigation to verify the AirModel simulation. This method can be applied in Energy Plus and other simulation tools/software to simulate the building exhaust energy recovery.

Acknowledgements

The work of this paper was sponsored by Texas A&M University, Physical Plant. We greatly appreciate support for this work from the Office of Energy Management and from other members of the Continuous Commissioning Group, Energy Systems Laboratory, Texas A&M University.

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