Modeling and Simulation of HVAC System Fault

Prahlad Patel[1], Hamant Amhia[2]

[1]Government Jabalpur Engineering College
M.E Electrical Control System
prahlad_patel2007@yahoo.com

[2]Government Jabalpur Engineering College
Department Electrocal Control System
hamant.amhia@jec-jablpur.org

Abstract: ***One of the big challenges in comparing Measured and simulated energy performance of buildings is that most energy models do not capture the significant impact of installation, operational and degradation HVAC system faults on actual energy performance in buildings. Energy Plus, a comprehensive whole building performance simulation tool, also has limited capability of modeling HVAC faults. The research described in this paper identifies, characterizes and prioritizes common faults of HVAC equipment and control systems, some of which are incorporated in Energy Plus. This research primarily supports the objective of assessing the effect of HVAC faults on whole building performance energy consumption and occupant comfort for use in retrofit decision analyses for existing buildings***

Keywords: HVAC, Energy Performance, Control Systems, Energy Consumption, Retrofit Decision Analysis

1. Introduction

With the growing focus on reducing energy use of existing buildings, the use of energy simulation tools for retrofit analysis and in support of retro commissioning activities has become increasingly important. However, all current simulation tools suffer from assumptions that control strategies work as designed, and HVAC equipment performs as rated. Several studies have shown that this is not the case. When studying the discrepancy between measured and simulated building energy performance, noted that an excess energy use within the building of up to 12% could be attributed to HVAC equipment not operating as specified, building conduction heat losses in excess of design stage predictions and minimum outdoor air intake differing from design values. As characterized by Haves (1997), these faults can either be abrupt, like a temperature sensor that suddenly fails, or they can develop over time, like a temperature or humidity sensor drifting over time, also called degradation faults. Fouling of heat exchange devices is another example of degradation faults. However, here we use the terminology, and deal only with, abrupt and degradation faults .Given that industry readily acknowledges buildings are not operated or controlled ideally, it is to be expected that there would be wide differences between measured and predicted energy performance of buildings.

2. Identification of Common HVAC Faults

Several sources of information regarding commonly occurring HVAC faults were identified. The most useful source found was a report produced by IEA. These three studies covered common faults in secondary HVAC [2] systems, fouling in heat exchangers and faults related to chillers respectively. Comstock and Brown also presented results on the frequency of occurrence and cost of repair of chiller faults in addition to identifying the most commonly found ones. While it is not possible to implement models of all the faults identified in this project in a whole building simulation program, a number of them were selected for Energy Plus implementation based on their energy or comfort impact and their relative frequency of occurrence. In the interest of time, prioritization weightings was also assigned to the ease of implementation of the faults in Energy Plus. Faults that require more detailed and complex models will be implemented in the next phase of this project. Very little in terms of research has been conducted in the area of modeling strategies for common HVAC faults. Haves (1997) described two primary methods for developing quantitative models of faulty HVAC component behavior. One is the ‘first principles model’ i.e. a model based on a scientific analysis of the process, and the second is an empirical or black box model’ that can be described by a neural network. As was further discussed by Haves (1997), faults may either be described by their effect on the performance of the component, or by their physical nature. It should note that the development of fault models is hampered by the scarcity of measured data on the effects of individual faults on performance of HVAC equipment. Modeling strategies for each of these four faults are discussed in the next section. These modeling strategies are based on simplifying assumptions due to the lack of quantitative data in this area. Some faults require the addition of model parameters to specify fault severity while a few are simulated by modifying the parameters of the correct operation model. The faults that have been implemented in Energy Plus are clogging of pipes in the plant loop, fouling of water heating coils, leaking outside air economizer dampers and zone temperature sensor offset.

3. Components Faults Symptoms

Boiler Fouled water tube Decreased boiler efficiency due to the increased thermal resistance of water tubes Boiler Steam pressure sensor out of calibration Higher than expected flue gas temperatures result in reduced boiler efficiency if the sensor has negative offset. Lower than desired steam pressure if the sensor has positive offset. Chiller Fouled condenser Decreased chiller efficiency and increased condenser outlet temperature Chiller Refrigerant leak Reduced condenser pressure and compressor capacity, lead to inefficient cooling Heating/Cooling coil Valve or actuator stuck open or close Unneeded simultaneous heating or cooling can occur if valve stuck open. If stuck closed, comfort penalty due to no heating or cooling when required Heating/Cooling coil Fouled coil Reduced UA reduces coil capacity. Increases pump power (compensated for by reduced load) Fan Stuck at full/intermediate speed, fails to respond to control signal Higher energy consumption if fan is stuck at speed higher than required. Reduced indoor air quality when it is stuck at lower speed Mixing box Stuck outdoor air damper Outdoor air damper cannot modulate, resulting in energy penalty when outdoor air conditions are favorable for free cooling or minimum outdoor air is demanded for mechanical heating/cooling modes Mixing box Leaking outdoor air damper Result in energy penalty when leakage rate is higher than the demanded outdoor air-flow rate. The energy impact may or may not be significant depending on system type, economizer type and building location. Temperature sensor offset (SAT, RAT, OAT) Outdoor air damper, return air damper and heating/cooling valve improperly controlled, resulting in energy penalty and thermal comfort issues. Water distribution system clogging inside the pipe Increase in the loop pressure drop causes higher energy consumption. Possible comfort issues due to insufficient water flow rate in the plant loop Pump Stuck at full/intermediate speed, fails to respond to control signal higher energy consumption if pump is stuck at speed higher than required. Reduced indoor air quality when it is stuck at lower speed Water distribution system Poor pipe insulation/condensation on pipe Depending on the location of the piping, can cause higher energy consumption due to thermal losses. Possible maintenance issue due to condensation on the chilled water pipe surface VAV Box VAV damper stuck Can cause significant simultaneous heating and cooling and comfort issues depending on which position the damper is stuck at VAV Box Fouled reheat coil (water side) Reduced heat transfer coefficient reduces coil capacity. Increased pump power (compensated for by reduced load) VAV Box Clogged/dirty reheat coil (air side).

4. Energy plus implementation

Energy Plus in its current form can be used to mode faulty component systems and sub-systems directly as done in the study. However, direct modeling of faulty HVAC components can be a laborious and inflexible process. It limits users to modifying existing model input variables and requires the user to be extremely well versed with component models within the program. This limitation places an unnecessary burden on the user and can be a barrier to the simulation of faulty operations. Energy Plus also offers the use of a scripting language called the Energy Management System (EMS). EMS is primarily intended to be used for implementing control strategies within buildings. Some of the faults discussed above can be modeled using the EMS runtime language scripting facility. However, EMS scripting is meant for advanced users of Energy Plus. EMS requires users to write their own control logic and, in most cases, has the limitation of only overwrite schedules during run time. Not all fault modeling [1] strategies require only runtime modification of schedules .Reusable fault models objects on the other hand do not require knowledge of internal component model implementation in Energy Plus . They relieve the user of the burden of identifying modeling strategies for the faults to be simulated .A new group of fault modeling objects has been created. Adding new simulation objects to Energy Plus is a two step process. In the first step, an input data structure for each new model is defined. Another important aspect of the reusable fault model objects is the ability to distinguish between abrupt and degradation faults. Fault type is an input parameter that is part of the IDD structure for each fault model. The treatment of each fault model varies depending on its type. When a fault is described to be abrupt in nature, the applicability schedule is applied as an on-off schedule. The fault will be simulated starting from the time the schedule has a value of 1 and the building will be simulated to operate normally for a value of 0. In case of a degradation type of fault, the schedule can take a fractional value and will allow the user to model an HVAC fault getting progressively worse over time. Implementation was carried out for each of the four fault models described in the previous section in a development version of Energy Plus. Once these models and implementation strategies have been vetted and approved by the full Energy Plus development team, they will be part of future official Energy Plus release versions.

5. Assessment of fault impacts

A preliminary assessment of the energy impacts of the faults was carried out using the large office building model that is part of the DOE Commercial Reference Building Models (DOE, 2011). These standard reference models are created to represent ‘typical’ buildings found across the building stock in the India covered by the Commercial Buildings End-Use Consumption Survey administered by the Energy Information Agency (EIA, 2011). The reference models are intended to represent roughly 70% of the commercial building stock in the India . The assessment was carried out for two representative climates. The large office building model is a twelve storey 12000 square foot building that is constructed with one core and four perimeter zones on each floor. It has a standard overhead VAV system for each floor with one boiler and two chillers in the plant loop. The results show the percentage change in HVAC cooling, heating, pump energy and the total HVAC energy use as compared to the baseline. A positive number represents an energy penalty .A baseline or reference simulation run was carried out. Each fault model was added to this baseline and simulated individually. Finally, all fault models were added to the large office building and the combined model was simulated. For the sensor offset fault, both positive and negative offsets for the zone sensors were simulated as separate cases. As regards the severity of the faults simulated, pipe clogging was simulated to cause a 20% increase in the chilled water loop total pressure drop at design conditions and a leakage flow fraction of 20% was specified for the leaking damper fault. A degradation of 20% in the India was specified for the fouled heating coil and offsets of 0.5 K and -0.5 K were specified for positive and negative sensor offset fault Model .The results agree qualitatively with the expected behavior of each fault model. As expected, we only see increase in cooling energy use for a positive sensor offset and the case of all faults combined case with positive sensor offset. Pump power increase also ranges from 0.2% to 2.8% based on the fault simulated. We see a decrease of energy use for heating when cooling increases or vice versa in certain cases. Therefore, the zone heating set point cannot be maintained, particularly on some colder days. It is observed that there is a 20% comfort penalty calculated based on the time the zone set point was not met during occupied hours for heating. The heating also shows generally higher numbers ranging from 2% to 21% for the cases of negative sensor offset and when the negative offset is combined with the other fault models. Pump energy shows relatively similar behavior as in Chicago with a range from 0.04% to 3.6% increases for certain faults. Similar to Chicago, the heating coil fouling also results in a modest increase in the number of heating unmet hours. The results also give us a general idea of the magnitude of the energy performance penalty imposed due to each type of fault. Sensor offsets have the greatest energy impact followed by damper leakage, pipe clogging and heating coil fouling in that order. However, the energy penalty depends on the severity of each fault.

6. Conclusion

A number of common HVAC equipment faults were identified and detailed fault models were generated for four of them. These fault models have been added to a developmental version of Energy Plus. The four fault models were tested for accuracy of implementation. The results indicate that the presence of HVAC faults can influence total HVAC energy use by as much as 22%, depending on the type of faulty behavior and the severity of the faults under consideration. Results from simulations carried out using fault models can also be used to help identify faulty behavior from a set of measured data, as well as for developing automated fault detection and diagnosis system.

References

[1] Fault modeling in component-based HVAC simulation, Proceedings of Building Simulation 1997, Prague, Czech Republic, IBPSA IEA.

[2] Shun, L., 2009, A Model- Based Fault Detection and Diagnostic Methodology for Secondary HVAC