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Date: November 6, 2014

Re: Energy Savings Predictions for HVAC Code Proposal

Introduction

The intent of this modeling exercise is to determine the potential impact of mechanical system selection on annual energy use for a variety of building occupancy types. In particular, the study was designed to get a rough understanding of the available savings associated with a proposed suite of Washington State Energy Code (WSEC) changes intended to impact the way mechanical engineers design HVAC systems for buildings.

Three case study buildings were chosen for this analysis including a school, office building, and fire station. These buildings were selected because they were designed using the approach suggested by the proposed code amendments, detailed energy models had already been developed, and/or good billing data existed for calibration purposes. Additionally, the three occupancy categories are fairly common, while representing extremely different usage profiles in terms of occupant density and activities. For example, fire stations are 24-7 facilities with sleeping units, dining and work-out facilities, and apparatus bays, whereas office spaces include moderate occupant density for roughly 60 hours/week and schools have very high occupant densities with moderate equipment loads. Showing that the proposed design measures provide substantial savings for varied building types demonstrates that the measures are broadly applicable.

King County Housing Authority New Office, Tukwila, WA 2012. EUI: 27 kBtu/sf-yr

RFM Architecture & Planning: Greg Belding, (360) 377-8773

This project is a complete interior renovation of a former big box retail store that brings together previously separated departments and promotes an integrated agency culture. The 36,000 sf remodeled space contains all major functions of a typical modern office. The project goals were to create an affordable energy efficient design. The design team delivered this for a total cost of $95/sf using readily available off- the-shelf technology. As part of this package the HVAC system was delivered for about $16/sf or less than 20% of the construction budget. Energy efficiency features include new double low-e insulated glazing systems, high efficiency crossflow Energy Recovery Ventilation(ERV), Variable Refrigerant Flow (VRF) 50-zone heat pump system, dimming lighting controls for corridors and perimeter daylit lighting zones, and occupancy controls on all lights in rooms with doors. The HVAC system is setup so that each room and office space has its own zoning with temperature control and override. This office uses 70% less energy than the national average office building (CBECs).

Eastside Fire & Rescue Station 72. Issaquah, WA. 2010. EUI: 25 kBtu/sf-yr

TCA Architecture: Brian Harris, (206) 522-3830

This project uses only 1/4 of the energy of a typical regional fire station; achieving an Energy Use Index (EUI) of 25 kBtu/sf-yr. The project earned a **LEED Platinum** certification. The project meets these ambitious targets through the use of super-insulation, heat recovery ventilation, a ground source heat pump system, radiant floor heating and cooling, solar water heating, high efficiency appliances, advanced lighting design and controls, and real-time energy use feedback to the occupants.

Westside School. Seattle. 2014 (under construction) Target EUI: 19 kBtu/sf-yr.

SKL Architecture: Gladys Ly-Au Young, (206) 322-1130

This project is the transformation of an existing church building into a private K-8 school. The finished building will include 55,000 SF of conditioned space with classrooms, a gymnasium, a performance hall, a cafeteria, circulation space, and office and conference spaces for staff. The predicted EUI is 19 kBtu/sf-yr. Regionally, the median EUI for new K-12 schools is about 60 kBtu/sf-yr (NEEA, CBSA).

There are three main changes intended to shift the way engineers approach mechanical system design that were included in the models. A more detailed description can be found in the memo titled HVAC Code Development Memo.

- Dedicated Outdoor Air Systems (DOAS)

  DOAS require that ventilation air is supplied by equipment that is separate from the systems heating and cooling the space. Ventilation air flow rates are sized to meet the ASHRAE 62 requirements. The DOAS systems include either an energy recovery ventilator (ERV) or demand control ventilation (DCV). The measure includes restrictions on fan power and thermal effectiveness of the ERV.

- Zoning

  Zones are defined as a space in a building separated by full height walls and doors from adjacent spaces, to prevent simultaneous heating and cooling. Each zone must have its own heating and cooling controls. DOAS systems separate the heating and cooling system from the ventilation, which allows the heating and cooling systems to cycle with the load in the space. When the temperature in the conditioned space is near the setpoint, the heating and cooling equipment is off. Additionally, separate setpoints are required for heating and cooling to prevent systems from cycling between heating and cooling operation.

- Equipment Sizing

  Equipment has been restricted to 1.25% of the load for heating and 1.15% of the peak load for cooling and 130% of the code ventilation flow rates.

Modeling Methodology

Existing eQUEST models developed for the case-studies previous to this modeling study were used as the starting point for the exercise. The existing models were as close as possible to the actual building architectural and mechanical system designs. Billing data is available for the King County Housing Authority and Fire Station 72 as both buildings have been fully occupied for more than two years. The existing models were calibrated to the billing data by adjusting occupancy, plug, and lighting schedules until the model output was within 5% of the billing data. The Westside School is still in construction, so schedules were based on audits performed of their existing facility and standard school schedules. After calibration, the envelope and lighting inputs for each building energy model were updated to match the most stringent requirements of either the 2012 version of the WSEC or the 2015 version of the IECC. Each building was then modeled with two separate code compliant HVAC systems that are commonly used for those occupancy types. Table 1 shows the HVAC system modeling matrix for the three case studies. More detail on modeling inputs can be found in the appended spreadsheets.

Table 1: Description

Case Study	Real World System	Code System 1	Code System 2
King County Housing Authority	VRF Heat Pumps w/ DOAS (ERV)	Packaged Roof Top Heat Pump Units, modeled w/ System 9 (PSZHP) inputs from WSEC performance path	Packaged VAV RTU w/ Parallel Fan Powered Terminal Units and Electric Re-heat. Modeled w/ System 3 inputs from 2015 IECC.
Fire Station 72	Ground Loop HX serving Water to Water Heat Pumps, radiant distribution with DOAS (ERV)	Ground Loop HX serving constant volume water to air heat pumps.	Water Source Heat Pumps w/ Fluid Cooler and Electric Boiler. Modeled with System 6 inputs from 2015 IECC
Westside School	VRF Heat Pumps w/ DOAS (ERV)	Packaged Roof Top Heat Pump Units, modeled w/ System 9 (PSZHP) inputs from WSEC performance path	Single Zone Gas Unit Ventilators

- Envelope

  Envelope U-factors were held constant at code levels across all three HVAC systems in each case study to isolate the effects of the HVAC systems on the energy use. 2012 WSEC U-factors were used, because they were more stringent than the 2015 IECC values. The only variation in the U-factors between the different buildings was in the slab insulation. Fire Station 72 included radiant (heated & cooled) floors, which requires continuous insulation below the slab. The F-factor actually increases from 0.54 for un-heated to 0.65 for heated due to increased heat transfer through the slab even though the insulation levels increase.

- Lights

  The building area method was used in all the models, which means that all spaces are modeled with a single lighting power density (LPD), rather than modeling each space with a unique value. LPDs were taken from the 2015 IECC Table 405.5.2(1), as they were more stringent than the 2012 WSEC values.

- Plugs

  Plug loads were based on values taken from building audits during the design process for each of the buildings.

- Schedules

  Schedules for the King County Housing are based on the standard National Renewable Energy Lab (NREL) prototype schedules for office buildings, but edited to calibrate the modeling output with billing data. Schedules for Fire Station 72 are based on several fire station audits performed for the City of Seattle and then tweaked to calibrate the model outputs with billing data. Schedules for the Westside School are from the 2012 Seattle Energy Code RS-29 code compliance path.

- Sizing

  The two code models in each building were sized at 1 CFM/SF, a rule of thumb commonly used by HVAC system designers and installers. This is roughly equivalent to 400 SF/ton. The DOAS models followed the 115% of peak cooling or 125% of peak heating load called out in the proposed code path.

- Ventilation

  The outdoor air flow rates for models with packaged equipment were set at 18%, which is the average value found by Ecotope in large scale PRTU studies. The DOAS models were set at 130% of the ASHRAE 62 minimum requirements.

Results

Table 2 shows the predicted EUI for each system. See the matrix in Table 1 for a detailed description of each system. Total energy annual energy savings for the proposed DOAS code path range from just under 30% for FS 72 to nearly 60% for the Westside School, depending on the system. To be clear, this is savings of the total building energy use, not only HVAC savings. One interesting result to note is predicted energy use for the code compliant systems was much lower than generally found in real world buildings with similar systems before outdoor air flow rates and fan sizing were brought up to median levels. The usual components that result in the inconsistencies between modeled performance and actual performance have been outdoor air flow rates, fan controls, simultaneous heating and cooling, and equipment sizing. In contrast, the KCHA & FS 72 models of the actual systems were within 10% of actual billed performance without calibration.

Table 2: Description

Case Study	As Designed System EUI (kBtu/sf/yr)	Code System 1 EUI (kBtu/sf/yr)	Code System 2 EUI (kBtu/sf/yr)
King County Housing Authority	30	66	70
Fire Station 72	33	56	67
Westside School	16	33	28

Figure 1 shows the area-normalized annual energy use for the King County Housing Authority office building. The largest savings between the VRF-DOAS model and the PRTU-HP model is in the ventilation energy. This is because the ductless VRF indoor fan coils have extremely low fan power, as low as 0. 07 W/CFM for many ceiling cassettes and wall hung units. In contrast, code compliant fan power for a ducted roof-top heat pump is more than 10 times higher at 0. 76 W/CFM. The larger fans also add more heat to the air-stream which increases cooling energy, and reduces the amount of the space heating performed by the heat pump section of the RTU. Space cooling energy is still reduced slightly, even with the increased fan heat, due to the economizers on the PRTU-HPs, which are not included on the VRF-DOAS system. The VAV system significantly increased both the heating energy use because of the lack of COP on the electric resistance heat in the parallel fan powered boxes and increased the ventilation energy use due to the larger and less efficient centralized fans.

Figure 1: King County Housing Authority EUI by End-Use

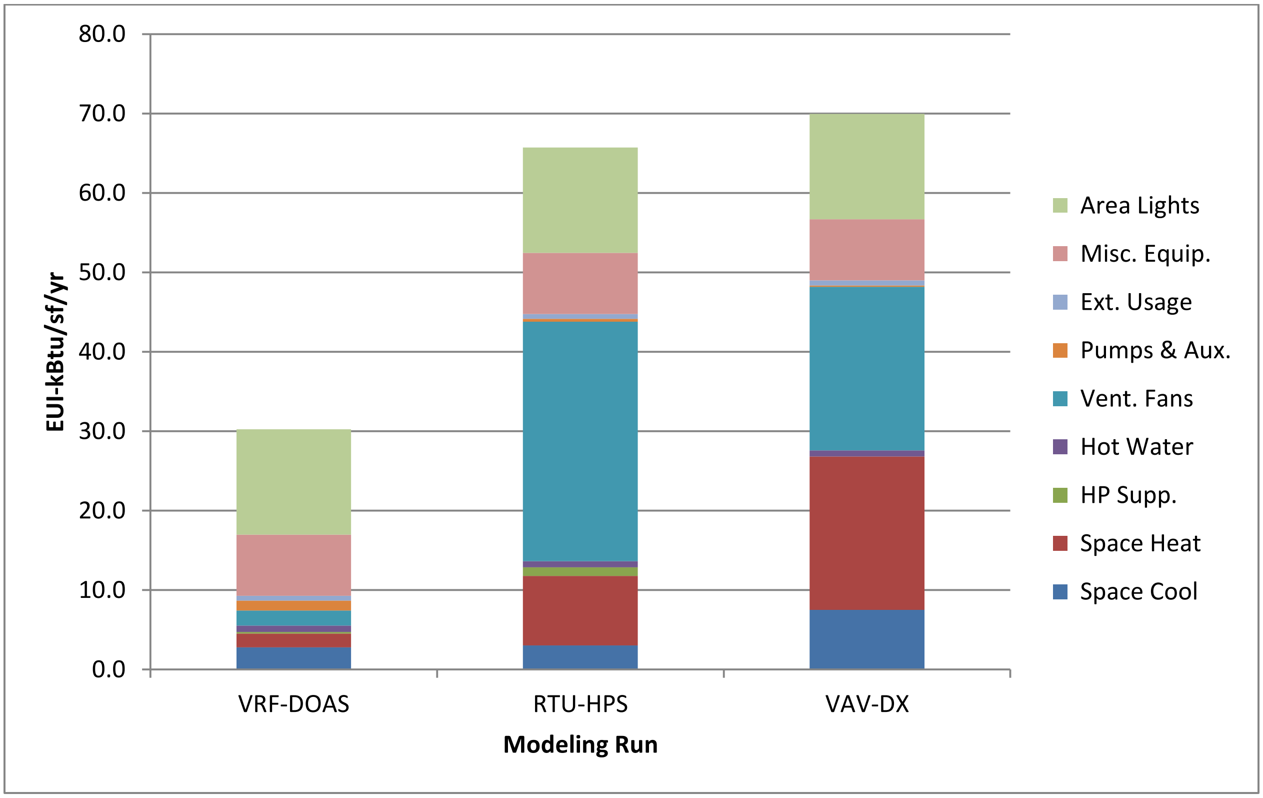

Figure 2: Fire Station 72 Modeling EUI by End-Use

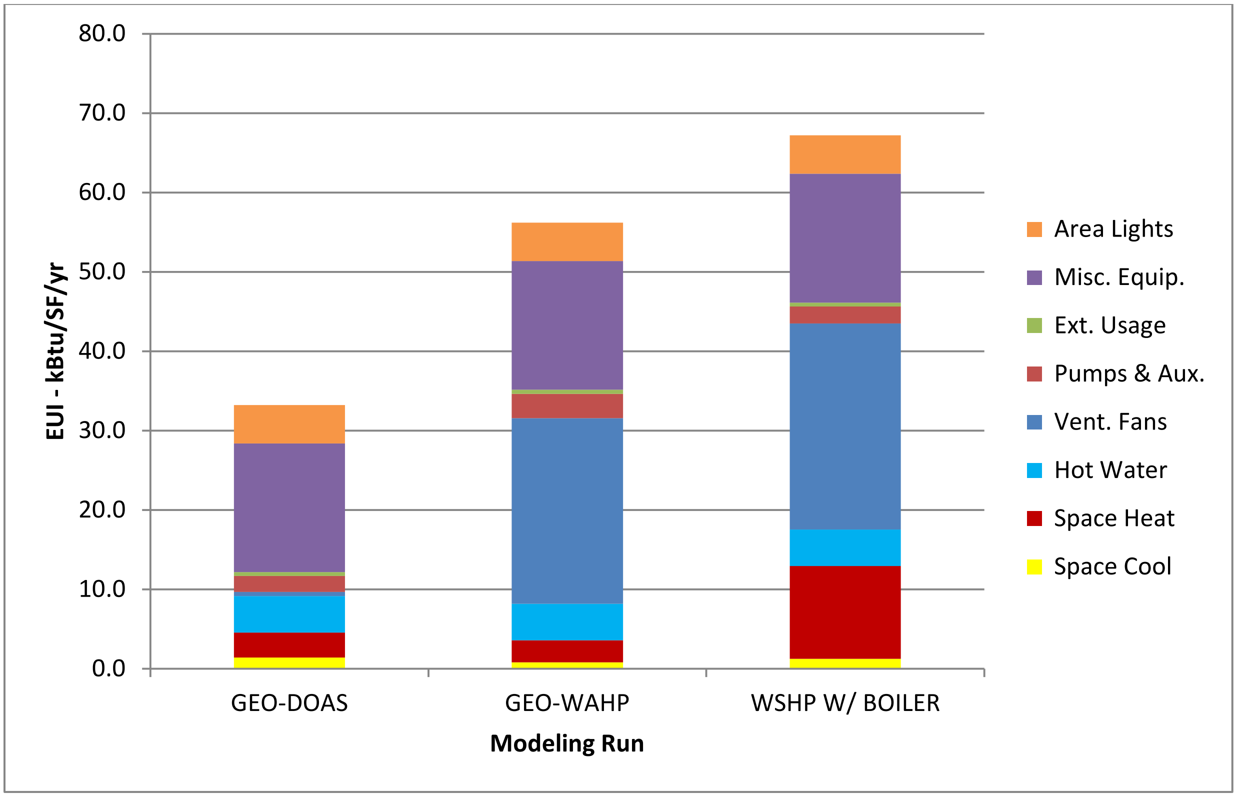

Figure 2 shows the comparison between water to water heat pumps serving a radiant distribution system (as-built) and water to air heat pumps with outside air economizers (Code) for Fire Station 72. Both systems have very high annual heating efficiency, with COPs above 3, but the standard code system has relatively high fan power (0. 76 W/cfm) operating continuously. The pumps in the as-built distribution system operate at a fraction of the power per Btu delivered, and cycle with load. Added fan heat offsets heating energy in the water to air heat pump system, which ends up being roughly equal to the energy saved with the air to air heat exchanger in the as-built system. The second code compliant system, a California heat pump loop with a fluid cooler and electric heat, significantly increased the space heating energy use, without changing the ventilation energy use compared to the water to air heat pump system.

Figure 3 shows the area-normalized energy use broken up by end-use for the Westside School. The largest savings between the as-built system and the gas furnace model are in space heat. This makes sense as the code gas heating thermal efficiency is 80%, and the seasonal heating efficiency of the VRF heat pumps approaches a COP of 3.5. Additionally, the code compliant gas furnace system does not require an energy recovery ventilator which further increases the space heating energy use. The next most significant savings is in the fan energy use, which is attributed to increased fan power in the code model (0. 76 W/CFM vs 0.00013) and the fact that the heating and cooling fans shut off when the space is at setpoint in the VRF-DOAS system. The same two end-uses, space-heat and fan energy also account for the largest share of the savings between the VRF-DOAS system and the PRTU-HPs system, with the addition of electric back-up heating. The other end-uses are basically identical between all three models.

Figure 3: Westside School EUI by End Use