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# Commercial Integrated Heat Pump with Thermal Storage --Demonstrate Greater than 50% Average Annual Energy Savings, Compared with Baseline Heat Pump and Water Heater (Go/No-Go)– FY16 4th Quarter Milestone Report


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MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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# Title

## BTO Project 3.2.2.12
## FY16 4th Quarter Milestone Report

## Commercial Integrated Heat Pump with Thermal Storage (C-IHP-TS) - Demonstrate Greater than 50% Average Annual Energy Savings, Compared with Baseline Heat Pump and Water Heater

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**Demonstrate Greater than 50% Average Annual Energy Savings, Compared with Baseline Heat Pump and Water Heater (Go/No-Go)**

## Executive Summary

For this study, we authored a new air source integrated heat pump (AS-IHP) model in EnergyPlus, and conducted building energy simulations to demonstrate greater than 50% average energy savings, in comparison to a baseline heat pump with electric water heater, over 10 US cities, based on the EnergyPlus quick-service restaurant template building. We also assessed water heating energy saving potentials using ASIHP versus gas heating, and pointed out climate zones where AS-IHPs are promising.

## EnergyPlus Building Energy Simulations

To facilitate this analysis, we developed a new AS-IHP model in EnergyPlus, which will be included in the upcoming EnergyPlus release, i.e. version 8.6. The most efficient operation mode of a commercial AS-IHP is the combined space cooling (SC) and water heating mode (SCWH). This mode makes effective use of both the heating and cooling outputs of the heat pump by recovering the condenser waste heat during SC operation for water heating (WH). We selected a quick-service restaurant template building (built after 1980) from the EnergyPlus example library, since it has the most frequent hot water draws and is able to facilitate extended SCWH running period.

The quick-service restaurant building is a single-story, two-zone building, having a floor area of 232 $m^2$ (2,500 $ft^2$). It has two HVAC systems, with one conditioning the kitchen area and the other conditioning the dining area. A 50 gallon, mixed water tank is used to supply hot water. We modified the EnergyPlus input file, using an AS-IHP to replace the HVAC system in the kitchen. Performance curves and efficiency indices of the AS-IHP was obtained from our residential AS-IHP development, i.e. the latest prototype made by Nortek. The performance was verified by our laboratory testing. A baseline system consisting of a heat pump, having a 14.0 SEER and 8.0 HSPF, and a conventional electric resistance storage water heater was used for comparison. In the cooling season, the kitchen space thermostat was set at 79°F (26°C) during occupied hours, and 86°F (30°C) during unoccupied hours. In the heating season, the thermostat was set at 66°F (19°C) during occupied hours and 60°F (15.6°C) during unoccupied hours. For heat pump water heating, an electric element controlled the tank temperature at 125.6°F (52°C), and the heat pump controlled it at 131°F (55°C), both having a 3.6 R (2 K) dead band. When running the baseline simulation, the electric element was used the same. It means that the HPWH targeted to deliver 5.4 R higher temperature of hot water than the electric resistance WH. To simplify the comparison, the AS-IHP and baseline heat pump only dealt with the indoor load. Loads induced by outdoor air ventilation was assumed to be handled by a separate dedicated outdoor air system.

We ran EnergyPlus simulations over 10 US cities, including Miami, FL, Houston, TX, Phoenix, AZ Atlanta, GA, Las Vegas, NV, Baltimore, MD, Chicago, IL, Los Angeles, CA, Seattle, WA, San Francisco, CA. The AS-IHP was auto-sized by EnergyPlus to match the design cooling load of each city. And thus, the required rated capacities range from 4.3 to 5.4 tons. Figure 1 illustrates indoor load distributions in the 10 US cities. It can be seen that the commercial kitchen's indoor loads are mostly dominated by cooling (SC) and water heating (WH). WH loads are comparable or even larger than SC loads in some mild climate zones.

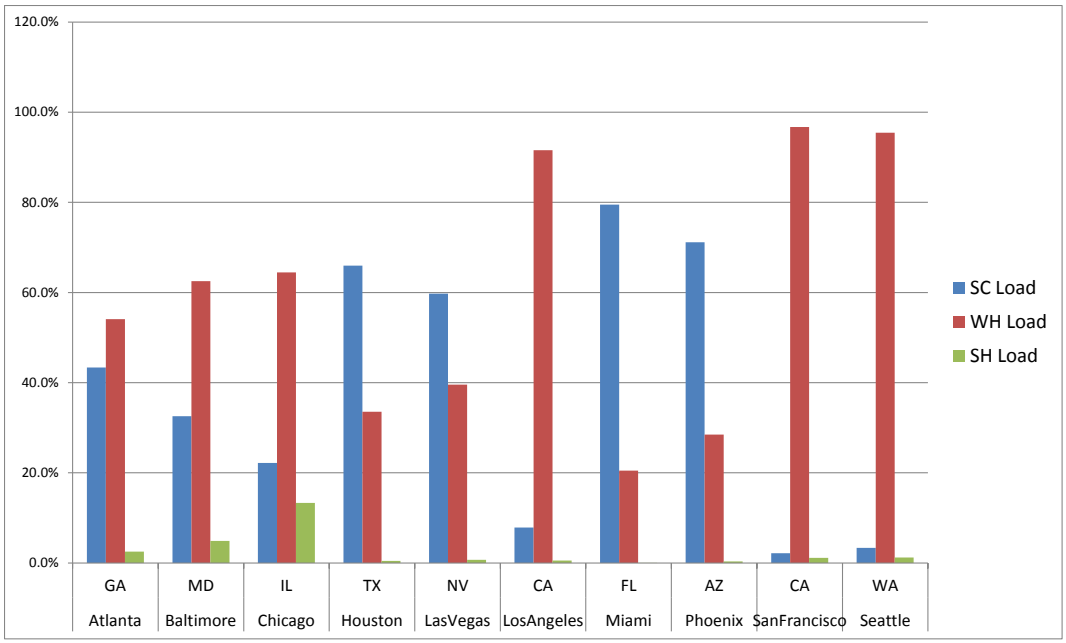


Figure 1. Internal Load Distributions in 10 US Cities

**Predicted Energy Savings, Compared to a Baseline Heat Pump with Electric Water Heater**

Figure 2 shows energy saving percentages of the AS-IHP versus the baseline heat pump with electric water heating. Table 1 contains the detailed statistics. It can be seen that all the cities, except Chicago, IL and Miami, FL, have annual energy savings over 50%. Los Angeles, CA, San Francisco, CA and Seattle, WA have energy savings over 60%, because restaurants in these three cities are WH load dominated.

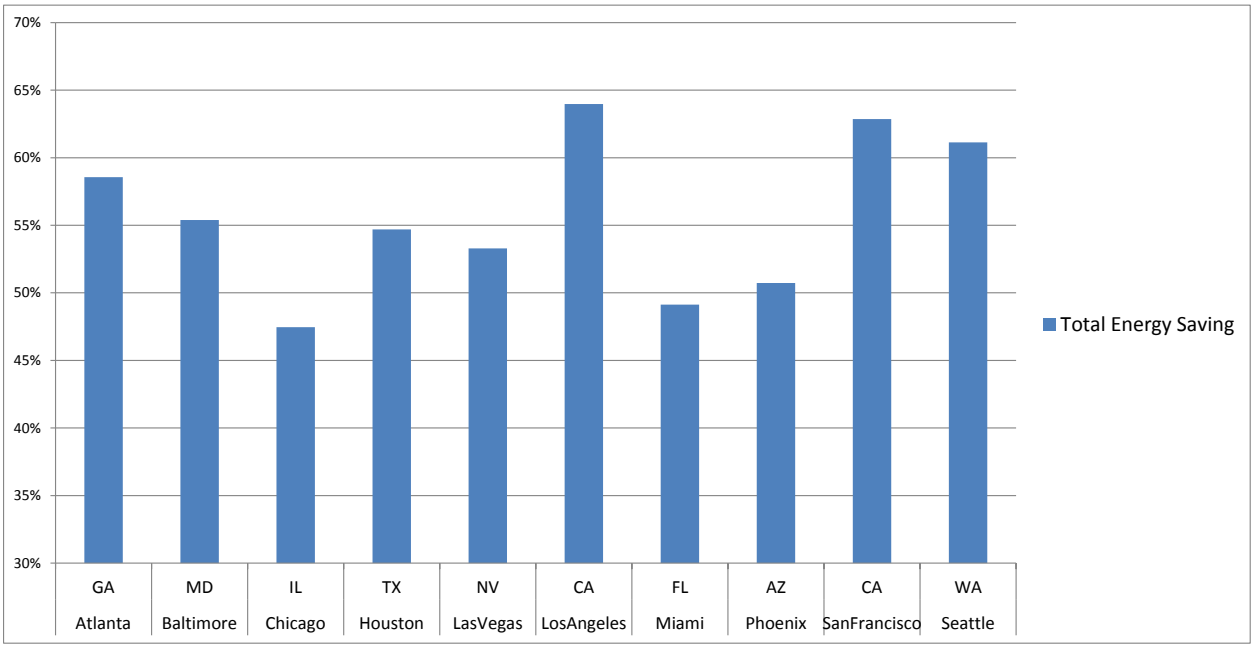


Figure 2. Total Energy Saving Percentages in 10 US Cities

Table 1: Building Energy Simulation Results of AS-IHP versus a Baseline Heat Pump with Electric Water Heating

| City | | Atlanta | Baltimore | Chicago | Houston | Las Vegas | Los Angeles | Miami | Phoenix | San Francisco | Seattle |
|---|---|---|---|---|---|---|---|---|---|---|---|
| State | | GA | MD | IL | TX | NV | CA | FL | AZ | CA | WA |
| Baseline | Total SC Delivery [kwh] | 12617 | 9020 | 6438 | 27007 | 21111 | 1318 | 45187 | 31339 | 385 | 633 |
| | Total WH Delivery [kwh] | 15737 | 17311 | 18692 | 13735 | 13980 | 15349 | 11658 | 12541 | 17062 | 18129 |
| | Total SH Delivery [kwh] | 737 | 1356 | 3865 | 197 | 251 | 93 | 11 | 158 | 197 | 230 |
| | Total Delivery [kwh] | 29091 | 27687 | 28995 | 40939 | 35342 | 16761 | 56857 | 44038 | 17644 | 18993 |
| | Total Energy Consumption [kwh] | 18936 | 20176 | 23060 | 19461 | 20477 | 15678 | 20739 | 21796 | 17223 | 18393 |
| | Total Electric COP [w/w] | 1.5 | 1.4 | 1.3 | 2.1 | 1.7 | 1.1 | 2.7 | 2.0 | 1.0 | 1.0 |
| AS-IHP | Total SC Delivery [kwh] | 11800 | 8482 | 6305 | 24143 | 19452 | 2694 | 40666 | 28096 | 766 | 1236 |
| | Total WH Delivery [kwh] | 15902 | 17473 | 18843 | 13900 | 14144 | 15516 | 11822 | 12704 | 17230 | 18301 |
| | Total SH Delivery [kwh] | 724 | 1362 | 3877 | 197 | 250 | 92 | 11 | 153 | 195 | 230 |
| | Total Delivery [kwh] | 28426 | 27318 | 29025 | 38241 | 33846 | 18302 | 52499 | 40953 | 18191 | 19768 |
| | Total Energy Consumption [kwh] | 7848 | 9000 | 12116 | 8817 | 9565 | 5648 | 10551 | 10739 | 6397 | 7148 |
| | Total Electric COP [w/w] | 3.6 | 3.0 | 2.4 | 4.3 | 3.5 | 3.2 | 5.0 | 3.8 | 2.8 | 2.8 |
| Total Energy Saving Percentage (AS-IHP vs. baseline) | | 59% | 55% | 47% | 55% | 53% | 64% | 49% | 51% | 63% | 61% |

**Compare AS-IHP Water Heating with Gas Water Heating**

AS-IHPs have a chance when competing with gas water heating, in mild and hot climate zones, where there are more simultaneous space cooling and water heating hours, and higher efficiency for dedicated heat pump water heating (DWH) mode.

Based on the EnergyPlus annual simulations, we calculated water heating source energy COPs, i.e. converting the electric COPs to source energy COPs by multiplying a factor of 0.32 (account for generation and transport loss using gas to generate electricity). To define the SCWH water heating COP, we need to split the power between the SC and WH operations. We first calculated the annual average COP of the SC mode, and assumed the power consumption share for space cooling during the SCWH mode is the total cooling capacity in SCWH mode divided by the SC annual COP. The remaining power consumption of the SCWH mode was attributed to water heating.

Figure 3 illustrates annual DWH source energy COPs, SCWH source COPs and integrated WH source COPs, i.e. sum of water heating capacities divided by sum of energy consumptions in DWH and SCWH modes. It can be seen that SCWH WH source COPs are much higher than the DWH COPs, as the condenser waste heat is recovered. The climate zones, having integrated WH source COPs higher than 1.0, are considered promising to use AS-IHPs and replace gas water heating. These are Houston, TX, Las Vegas, NV, Miami, FL, Phoenix, AZ.

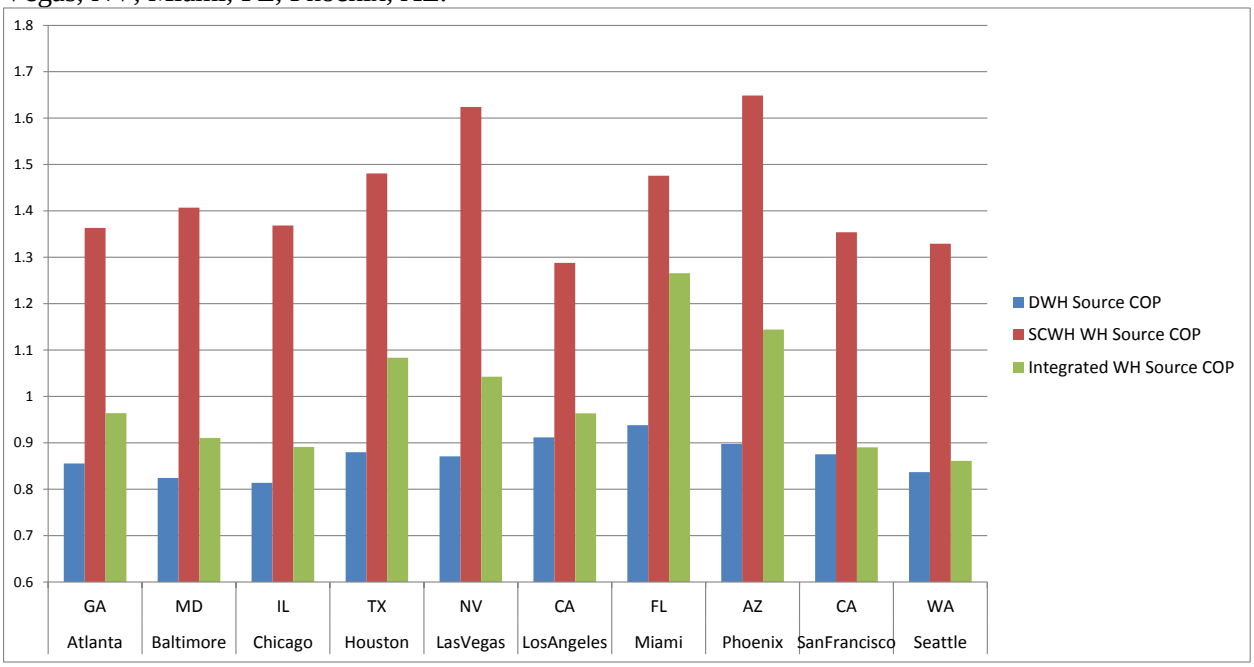


Figure 3. Water Heating Source Energy COPs in 10 US Cities

**Summary**

We developed a new AS-IHP model in EnergyPlus, selected a quick-service, restaurant template building and ran energy simulations over 10 US cities. In comparison to a baseline heat pump with electric water heating, the AS-IHP is able to achieve greater or approximately equal to 50% annual energy savings in all the cities. We also compared AS-IHP Water Heating with Gas Water Heating in terms of source energy efficiency, and proved that the AS-IHP water heating is more efficient in Houston, TX, Las Vegas, NV, Miami, FL, Phoenix, AZ.