ORNL/TM-2016/141

EnergyPlus Air Source Integrated Heat Pump Model

Bo Shen
Mark Adams
Joshua R. New

March 30, 2016

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

ORNL/TM-2016/141

Energy & Transportation Science Division

EnergyPlus Air Source Integrated Heat Pump Model

Bo Shen
Mark Adams
Joshua R. New

Date Published: March 30, 2016

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6283
managed by
UT-BATTELLE, LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

CONTENTS

Page

LIST OF FIGURES v
LIST OF TABLES ..... **Error! Bookmark not defined.**
ACRONYMS vii
ABSTRACT 1
1. INTRODUCTION 1
1.1 SIGNIFICANCE 1
1.2 MODEL DESCRIPTION 2
1.3 WORKING MODES 2
1.4 CONTROL AND MODE SWITCH 4
1.5 INPUT-OUTPUT REFERENCE 5
APPENDIX A. INPUT IDF EXAMPLES A-1

LIST OF FIGURES

Figure **Page**

Figure 1. Schematic of Air Source Integrated Heat Pump 1

ACRONYMS

ASIHP	Air Source Integrated Heat Pump
COP	coefficient of performance
DOE	U.S. Department of Energy
DWH	dedicated water heating
HVAC	heating, ventilating, and air-conditioning
IDF	inpuit data file
SC	space cooling
SCDWH	space cooling and water heating with desuperheating
SCWH	space cooling and water heating
SH	space heating
SHDWH	space heating and water heating with desuperheating
WH	water heating (function)

ABSTRACT

This report summarizes the development of the EnergyPlus air-source integrated heat pump model. It introduces its physics, sub-models, working modes, and control logic. In addition, inputs and outputs of the new model are described, and input data file (IDF) examples are given.

1. INTRODUCTION

1.1 SIGNIFICANCE

The Air Source Integrated Heat Pump (ASIHP) is an air source, multi-functional spacing conditioning unit with water heating function (WH), as shown in Figure 1, which usually uses a variable-speed compressor, variable-speed indoor blower, and outdoor fan. By recovering the condenser waste heat for water heating, ASIHPs are able to achieve significant energy savings. The U.S. Department of Energy (DOE) has invested in developing such an advanced, edge-cutting technology for years, and now it is ready to be launched to the market. Due to premium variable-speed compressors and fans applied, initial cost of an ASIHP is high. However, the payback period should be short due to its significant energy saving potential, i.e., >50%. In support of DOE's goal to promote energy saving technologies, EneryPlus needs to model operation and control mechanisms of ASIHPs, simulate annual energy savings, and estimate payback periods. This will provide justifications for end consumers to select the highly efficient product. Current version of EnergyPlus is able to simulate individual working modes of the ASIHP, i.e., variable-speed cooling coil (Coil:Cooling:DX:VariableSpeed), variable-speed heating coil (Coil:Heating:DX:VariableSpeed), and variable-speed water heating coil (Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed). Nonetheless, there is still lack of a feature to integrate these modes together and simulate the multi-functional ASIHP operations. EnergyPlus needs to add the feature of ASIHP to contain all the variable-speed, space conditioning, and water heating sub-models.

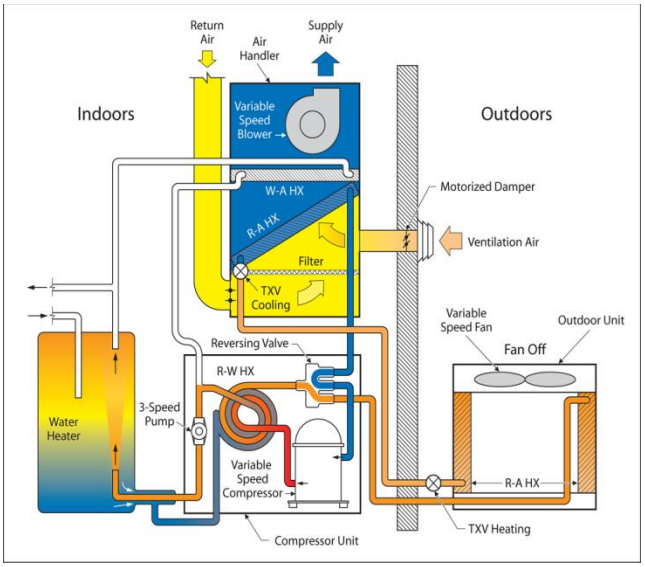

Figure 1. Schematic of Air Source Integrated Heat Pump.

1.2 MODEL DESCRIPTION

The latest technology for commercial air conditioners and air-to-air heat pumps can utilize a variable-speed compressor with a variable-speed indoor blower and outdoor fan. Integrated heat pumps are multi-functional units capable of space conditioning and water heating. They use condenser waste heat for water heating, and thus achieve significant energy saving. The control and operation of ASIHPs are complicated because they have six working modes in total: (1) space cooling (SC), (2) space heating (SH), (3) dedicated water heating (DWH), (4) combined space cooling and water heating with full condensing (SCWH), (5) combined space cooling and water heating with desuperheating (SCDWH), and (6) combined space heating and water heating with desuperheating (SHDWH). The SC mode has the same operation as the object of Coil:Cooling:DX:VariableSpeed. The SH mode has the same operation as the object of Coil:Heating:DX:VariableSpeed. The DWH mode uses outdoor air as the heating source, which can be represented by an object of Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed. The SCWH mode uses indoor air as the heating source and full condenser heat for water heating, which can be simulated using an object of Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed.

The SCDWH mode uses the superheated section of an outdoor condenser to heat the water. In this combined SCDWH mode, the cooling function is simulated using an object of Coil:Cooling:DX: VariableSpeed, containing temperature correction curves as a function of the indoor air and ambient temperatures at each speed level. The water heating function is simulated using an object of Coil:WaterHeating: AirToWaterHeatPump:VariableSpeed, having temperature correction curves as a function of the ambient air temperature and entering water temperature at each speed level. It should be noted that the rated power and power correction curves are contained in the Coil:Cooling:DX: VariableSpeed object. Thus, the power values and curves in the Coil:WaterHeating: AirToWaterHeatPump:VariableSpeed are not used. That means the power consumption at each speed level of the SCDWH mode is accounted by the cooling coil part.

The SHDWH uses the superheated section of an indoor condenser to heat the water. In this combined mode, the heating function is simulated using an object of Coil:Heating:DX:VariableSpeed, having temperature correction curves as a function of the indoor air and ambient temperatures at each speed level. The water heating function is simulated using an object of Coil:WaterHeating: AirToWaterHeatPump:VariableSpeed, having temperature correction curves as a function of the ambient air temperature and entering water temperature at each speed level. It should be noted that the rated power and power correction curves are contained in the Coil:Heating:DX:VariableSpeed object. Thus, the power values and curves in the Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed are not used. That means the power consumption at each speed level of the SHDWH mode is accounted by the air heating coil part. The Coil:Heating:DX:VariableSpeed object calculates the total heating capacity added to the indoor air flow. Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed calculates the total heating capacity added to the water stream.

The parent object of the ASIHP is named as CoilSystem:IntegratedHeatPump:AirSource, which is a collection of all the sub-models as above. Also, CoilSystem:IntegratedHeatPump:AirSource facilitates mode switch and control algorithms.

1.3 WORKING MODES

The ASIHP is a collection of working modes, i.e., objects, as described below:

Space Cooling Mode (SC):

--Coil object: Coil:Cooling:DX:VariableSpeed contained in CoilSystem:IntegratedHeatPump:AirSource. The air nodes in the coil object are allowed to be empty and then filled in with the nodes from the CoilSystem.

--Loop object: AirLoopHVAC:UnitarySystem, which refers to the CoilSystem:IntegratedHeatPump: AirSource object.
--Load matching: the same as a regular variable-speed air source heat pump in cooling mode.

Space Heating Mode (SH):
--Coil object: Coil:Heating:DX:VariableSpeed contained in CoilSystem:IntegratedHeatPump:AirSource. The air nodes in the coil object are allowed to be empty and then filled in with the nodes from the CoilSystem.
--Loop object: AirLoopHVAC:UnitarySystem, which refers to the CoilSystem:IntegratedHeatPump: AirSource object.
--Load matching: the same as a regular variable-speed air source heat pump in heating mode

Dedicated Water Heating Mode (DWH):
--Coil object: Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed contained in CoilSystem:IntegratedHeatPump:AirSource. The water heating coil uses outdoor air as the heating source. The air and water nodes in the coil object are allowed to be empty and then filled in with the nodes from the CoilSystem.
--Loop object: WaterHeater:HeatPump:PumpedCondenser, which refers to the CoilSystem:IntegratedHeatPump:AirSource object.
--Load matching: the same as a regular variable-speed heat pump water heating coil with outdoor air source.

Combined Space Cooling and Water Heating with Full Condensing Mode (SCWH):
--Coil object: Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed contained in CoilSystem:IntegratedHeatPump:AirSource. The water heating coil uses indoor air as the heating source. The air and water nodes in the coil object are allowed to be empty and then filled in with the nodes from the CoilSystem.
--Loop object:
-->Air side: the same loop object as the SC mode, i.e., AirLoopHVAC:UnitarySystem, which refers to the CoilSystem:IntegratedHeatPump:AirSource object.
-->Water side: the same loop object as the DWH mode, i.e., WaterHeater:HeatPump: PumpedCondenser, which refers to the CoilSystem:IntegratedHeatPump:AirSource object.
--Load matching:
-->If one chooses to match the space cooling load, iterate the AirLoopHVAC object, and the water heating capacity in the water tank object is resultant.
-->If one chooses to match the water heating load, iterate the water tank object, and the space cooling capacity is resultant.

Combined Space Cooling and Water Heating with Desuperheating Mode (SCDWH):
--Coil object: use two coil objects, Coil:Cooling:DX:VariableSpeed and Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed, contained in CoilSystem:IntegratedHeatPump: AirSource. The desuperheater heat is used for water heating, which changes with the compressor speed and operation conditions. This is a dual-function coil, which provides both space cooling and water heating, and so performance curves for the dual functions will be included in the coil objects, respectively. These should be different objects from the SCWH mode and SC mode. The water heating coil contains temperature correction curves as a function of the ambient air temperature and entering water temperature. The air and water nodes in the coil object are allowed to be empty and then filled in with the nodes from the CoilSystem.

It should be noted that the rated power and power correction curves are contained in the Coil:Cooling:DX:VariableSpeed object. Thus, the power values and curves in the

Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed are not used. That means the power consumption at each speed level of the SCDWH mode is accounted by the cooling coil part.
--Loop object:
-->Air side: the same loop object as the SC mode, i.e., AirLoopHVAC:UnitarySystem.
-->Water side: the same loop object as the DWH mode, i.e., WaterHeater:HeatPump:PumpedCondenser.
--Load matching:
Always match the space cooling load by iterating the AirLoopHVAC object, and the water heating amount in the water tank object is resultant.

Combined Space Heating and Water Heating with Desuperheating Mode (SHDWH):
--Coil object: use two coil objects, Coil:Heating:DX:VariableSpeed and Coil:WaterHeating: AirToWaterHeatPump:VariableSpeed, contained in CoilSystem:IntegratedHeatPump:AirSource. The desuperheater heat is used for water heating, which changes with the compressor speed and operation conditions. This is a dual-function coil, which provides both space heating and water heating, and so performance curves for the dual functions will be included in the coil objects, respectively. The air nodes in the coil object are allowed to be empty and then filled in with the nodes from the CoilSystem.

It should be noted that the rated power and power correction curves are contained in the Coil:Heating:DX:VariableSpeed object. Thus, the power values and curves in the Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed are not used. That means the power consumption at each speed level of the SHDWH mode is accounted for by the heating coil part.

The Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed object contains rated water heating capacity and capacity correction curves to simulate water heating capacity as a function of the outdoor air temperature and the water entering temperature at each speed level. The Coil:Heating:DX:VariableSpeed object calculates the total heating capacity, added to indoor air flow.
--Loop object:
-->Air side: share the same air side connections as the SH mode, i.e., AirLoopHVAC:UnitarySystem.
-->Water side: the same loop object as the DWH mode, i.e., WaterHeater:HeatPump:PumpedCondenser.
--Load matching:
Always match the space heating load by iterating the AirLoopHVAC object, and the water heating amount in the water tank object is resultant.

1.4 CONTROL AND MODE SWITCH

At the beginning of each time step, an CoilSystem:IntegratedHeatPump:AirSource object surveys calls from all of its connected parent objects and nodes, e.g., AirLoopHVAC:UnitarySystem, WaterHeater:HeatPump:PumpedCondenser. Upon analyzing the space conditioning and water heating calls, the ASIHP will operate in a selected mode for the following timestep, as shown below:

Case I:
If there is only a space cooling call – run SC mode.

Case II:
If there is only a space heating call – run SH mode.

Case III:
If there is only a water heating call, and if ambient temperature and indoor temperature are larger than the temperature settings above which indoor overcooling is allowed – run SCWH mode to match the water heating load above a minimum speed allowed.

Else – run DWH mode.

Case IV:

If there are simultaneous space cooling and water heating calls, and if the sum of heated water going through the ASIHP is less than the threshold – run SCDWH mode by iterating the speed to match the space cooling load above a minimum speed specified.

Else – run SCWH mode to match either the space cooling load or the water heating load, as specified, above a minimum speed allowed.

Case V:

If there are simultaneous space heating and water heating calls, and if the ambient temperature and indoor temperature are larger than temperature settings above which water heating has a higher priority and space heating call can be ignored – run DWH mode.

Otherwise, if running time of the water heating is less than a setting – run SHDWH mode to match the space heating load by iterating the compressor speed above a minimum speed specified, with the WH electric element in the water tank disabled.

Otherwise, if running time of the water heating is bigger than the setting – run SHDWH mode to match the space heating load by iterating the compressor speed above a minimum speed allowed, with the WH electric element enabled.

1.5 INPUT-OUTPUT REFERENCE

Input Description

The fields for each input objects are described as:

CoilSystem:IntegratedHeatPump:AirSource

CoilSystem:IntegratedHeatPump:AirSource is a collection of all the working modes in an air-source integrated heat pump, including space cooling (SC), space heating (SH), dedicated water heating (DWH), combined space cooling and water heating with full condensing(SCWH), combined space cooling and water heating with desuperheating (SCDWH), combined space heating and water heating with desuperheating (SHDWH). These working modes should also be referred to in other related air loop or water loop parent objects, for example, AirLoopHVAC:UnitarySystem and WaterHeater:HeatPump:PumpedCondenser, to represent the air side and water side node connections, and facilitate iterating the speed to match the space conditioning or water heating load. In addition, CoilSystem:IntegratedHeatPump:AirSource contains a series of criteria for selecting a working mode at the beginning of each timestep.

The input fields for this object are described below in detail:

Field: Name

This alpha field defines a unique user-assigned name for an instance of an air-source integrated heat pump.

Field: Indoor Air Side Cooling Coil Inlet Node Name

This alpha field defines an indoor air side node entering the cooling coil (SC) of the integrated heat pump.

Field: Indoor Air Side Heating Coil Inlet Node Name

This alpha field defines an indoor air side node leaving the cooling coil (SC) and entering the heating coil (SH) of the integrated heat pump.

Field: Indoor Air Side Heating Coil Outlet Node Name

This alpha field defines an indoor air side node leaving the heating coil (SH) of the integrated heat pump.

Field: Water Side Inlet Node Name
This alpha field defines a water side node entering the integrated heat pump.

Field: Water Side Outlet Node Name
This alpha field defines a water side node leaving the integrated heat pump.

Field: Supply Water Monitoring Node Name
This alpha field defines a water side node to monitor the supply water amount after the water heating operation of the integrated heat pump is turned on.

Field: Outdoor Air Side Inlet Node Name
This alpha field defines an outdoor air side node entering the outdoor coil of the integrated heat pump.

Field: Outdoor Air Side Outlet Node Name
This alpha field defines an outdoor air side node leaving the outdoor coil of the integrated heat pump.

Field: Space Cooling Mode Coil Name
This alpha field defines the space cooling (SC) mode in an ASIHP, which must be given. The SC mode refers to the name of a Coil:Cooling:DX:VariableSpeed object, which contains all the performance curves and rated values to describe the space cooling operation.

Field: Space Heating Mode Coil Name
This alpha field defines the space heating (SH) mode in the ASIHP, which must be given. The SH mode refers to the name of a Coil:Heating:DX:VariableSpeed object, which contains all the performance curves and rated values to describe the space heating operation.

Field: Water Heating Mode Coil Name
This alpha field defines the dedicated water heating (DWH) mode in the ASIHP, which must be given. The DWH mode refers to the name of a Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed object, which contains all the performance curves and rated values to describe the water heating operation with outdoor air source.

Field: SCWH Mode Coil Name
This alpha field defines the combined space cooling and water heating with full condensing (SCWH) in an ASIHP, which must be given. The SCWH mode refers to the name of a Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed object, which contains all the performance curves and rated values to describe the water heating operation with an indoor air source. The SCWH mode is connected to the same WaterHeater:HeatPump:PumpedCondenser as the DWH mode, and the same air side node connections as the SC mode.

Field: SCDWH Mode Cooling Coil Name
This alpha field defines the cooling operation in the combined space cooling and water heating with desuperheating (SCDWH) mode in an ASIHP, which must be given. These should be a different object from the SC mode. The air nodes in the coil object are allowed to be empty and then filled in with the nodes from the CoilSystem. It should be noted that the rated power and power correction curves are contained in the Coil:Cooling:DX:VariableSpeed object. That means the power consumption at each speed level of the SCDWH mode is accounted for by the cooling coil part.

Field: SCDWH Mode Water Heating Coil Name

This alpha field defines the water heating operation in the combined space cooling and water heating with desuperheating (SCDWH) mode in an ASIHP, which must be given. The water nodes in the coil object are allowed to be empty and then filled in with the nodes from the CoilSystem. The power values and curves in the Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed are not used. That means the power consumption at each speed level of the SCDWH mode is accounted for by the cooling coil part.

Field: SHDWH Mode Heating Coil Name
This alpha field defines the heating operation in the combined space heating and water heating with desuperheating (SHDWH) mode in an ASIHP, which must be given. This should be a different object from the SH mode. The air nodes in the coil object are allowed to be empty and then filled in with the nodes from the CoilSystem. It should be noted that the rated power and power correction curves are contained in the Coil:Heating:DX:VariableSpeed object. That means the power consumption at each speed level of the SHDWH mode is accounted for by the cooling coil part.

Field: SHDWH Mode Water Heating Coil Name
This alpha field defines the water heating operation in the combined space heating and water heating with desuperheating (SCDWH) mode in an ASIHP, which must be given. The water nodes in the coil object are allowed to be empty and then filled in with the nodes from the CoilSystem. The power values and curves in the Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed are not used. That means the power consumption at each speed level of the SHDWH mode is accounted for by the heating coil part.

Field: SCWH Mode Minimum Indoor Temperature to Allow Overcooling
This numeric field defines an indoor air temperature [C] above which indoor overcooling is allowed in the cooling operation, i.e., allowing running the SCWH mode to cool down the indoor air below the thermostat setting temperature, and iterate the compressor speed to match the water heating load. It has to be noted that both the indoor temperature and ambient temperature lower bound settings have to be satisfied when allowing indoor overcooling by running the SCWH mode.

Field: SCWH Mode Minimum Outdoor Temperature to Allow Overcooling
This numeric field defines an ambient air temperature above which indoor overcooling is allowed in the cooling operation, i.e., allowing running the SCWH mode to cool down the indoor air below the thermostat setting temperature, and iterate the compressor speed to match the water heating load. It has to be noted that both the indoor temperature and ambient temperature lower bound settings have to be satisfied when allowing overcooling the indoor by running the SCWH mode.

Field: Minimum Indoor Temperature to Ignore Space Heating Call
This numeric field defines an indoor air temperature [C] above which the water heating request has the higher priority and the space heating call can be ignored. The ASIHP will run the DWH mode to match the water heating load regardless of space heating call. It has to be noted that both the indoor temperature and ambient temperature lower bound settings have to be satisfied when a space heating call can be ignored.

Field: Minimum Outdoor Temperature to Ignore Space Heating Call
This numeric field defines an ambient air temperature [C] above which the water heating request has the higher priority and the space heating call can be ignored. The ASIHP will run the DWH mode to match the water heating load regardless of space heating call. It has to be noted that both the indoor temperature and ambient temperature lower bound settings have to be satisfied when a space heating call can be ignored.

Field: SCWH Mode Load Matching Type

This choice field specifies the control in the SCWH mode. The choices are CoolingLoad or WaterHeatingLoad. During the SCWH operation when both the space cooling and water heating calls exist, if the field is CoolingLoad, it means that the compressor speed is iterated to match the space cooling load, and the water heating energy is a byproduct. If this field is WaterHeatingLoad, it means that the speed is altered to match the water heating load, and the space cooling energy is a byproduct.

Field: SCWH Mode Minimum Speed
This numeric field defines a minimum speed level for running the SCWH; i.e., the compressor speed will be altered between the minimum speed specified and top speed, responding to the simultaneous space cooling and water heating calls. If there is only a water heating call, this input will not be used.

Field: SCDWH Mode Maximum Heated Water Volume Before Switching to SCWH Mode
This numeric field defines an accumulative, heated water volume [m^3] before switching from SCDWH to SCWH mode. When there are simultaneous space cooling and water heating calls, the ASIHP will run SCDWH first to satisfy a small water heating load. If the water volume heated by the heat pump goes beyond the limit, it means that the SCDWH, which uses a desuperheater, cannot provide enough capacity for the water heating request, and thus the SCWH mode will be turned on.

Field: SCDWH Mode Minimum Speed
This numeric field defines a minimum speed level for running the SCDWH; i.e., the compressor speed will be altered between the minimum speed specified and top speed to match the space cooling load, and the water heating energy is a byproduct.

Field: SHDWH Mode Time Limit Before Turning on Electric Water Heating Element
This numeric field defines the running time [s] of the SHDWH mode before electric heating elements in the connected water tank are turned on if the water heating request cannot be satisfied on time. When there are simultaneous space heating and water heating calls, the ASIHP will run SHDWH mode first to satisfy a small water heating load. If the running time goes beyond the time limit, it means that the SHDWH mode, which uses a desuperheater, cannot provide enough capacity for the water heating request, and thus the electric elements in the water tank will be turned on to supplement the heating capacity.

Field: SHDWH Mode Minimum Speed
This numeric field defines a minimum speed level for running the SHDWH mode; i.e., the compressor speed will be altered between the minimum speed and top speed to match the space heating load. Consequently, the water heating capacity is the byproduct.

Output Description
The output variables of **Air Source Integrated Heat Pump (**AISHP) alongwoth the description:

- HVAC, Average, Operation Mode []
- HVAC, Average, Air Loop Flow Rate [kg/s]
- HVAC, Average, Condenser Water Flow Rate [kg/s]
- HVAC, Average, Cooling Coil Total Cooling Rate [W]
- HVAC, Average, Heating Coil Total Air Heating Rate [W]
- HVAC, Average, Total Water Heating Rate [W]
- HVAC, Average, Total Electric Power [W]
- HVAC, Average, Total Latent Cooling Rate [W]
- HVAC, Average, Total Source Energy Rate [W]
- HVAC, Average, Total Coefficient of Performance (COP) []

- HVAC, Sum, Total Electric Energy [J]
- HVAC, Sum, Total Cooling Energy [J]
- HVAC, Sum, Total Air Heating Energy [J]
- HVAC, Sum, Total Water Heating Energy [J]
- HVAC, Sum, Total Latent Cooling Energy [J]
- HVAC, Sum, Total Source Energy [J]

Operation Mode []
This output variable is an integer representing the operation mode in the timestep.
Air Loop Flow Rate [kg/s]
The output variable is the air mass flow rate in the indoor air loop, over the timestep being reported.
Condenser Water Flow Rate [kg/s]
The output variable is the hot water mass flow rate through the condenser of the heat pump water heater, over the timestep being reported.
Cooling Coil Total Cooling Rate [W]
The output variable is the average total cooling load provided by the integrated heat pump, which includes the sensible and latent load in watts over the timestep being reported.
Heating Coil Total Air Heating Rate [W]
The output variable is the average total heating load provided by the integrated heat pump in watts over the timestep being reported.
Total Water Heating Rate [W]
The output variable is the average total water heating load provided by the integrated heat pump in watts over the timestep being reported.
Total Electric Power [W]
The output variable is the average total electric power consumed by the integrated heat pump in watts over the timestep being reported.
Total Latent Cooling Rate [W]
The output variable is the average latent cooling load provided by the integrated heat pump in watts over the timestep being reported.
Total Source Energy Rate [W]
The output variable is the average total source energy rate absorbed or discharged to the outdoor air by the integrated heat pump in watts over the timestep being reported.
Total COP []
The output variable is the average total COP (using the total delivered load divided by the electric power) by the integrated heat pump in watts over the timestep being reported. The total delivered load includes all the incurred space cooling, water heating, and space heating loads.
Total Electric Energy [J]
The output variable is the electric consumption of the integrated heat pump in joules over the timestep being reported.
Total Cooling Energy [J]
The output variable is the total space cooling output of the integrated heat pump in joules over the timestep being reported.
Total Air Heating Energy [J]
The output variable is the total space heating output of the integrated heat pump in joules over the timestep being reported.
Total Water Heating Energy [J]
The output variable is the total water heating output of the integrated heat pump in joules over the timestep being reported.
Total Latent Cooling Energy [J]

The output variable is the total latent cooling output of the integrated heat pump in joules over the timestep being reported.

Total Source Energy [J]

The output variable is the total source energy output of the integrated heat pump in joules, absorbed or discharged to the outdoor air, over the timestep being reported.

ACKNOWLEDGMENTS

The authors thank Mr. Amir Roth, Technology Development Manager for Building Energy Modeling, Emerging Technologies Program, Buildings Technology Office at the U.S. Department of Energy for supporting this research project.

APPENDIX A. INPUT IDF EXAMPLES

IDF Objects (new):

```
CoilSystem:IntegratedHeatPump:AirSource,
ASIHP1,     !- Name of an air-source integrated heat pump
AirInNode,     !- Name of the indoor air side cooling coil Inlet node
AirHeatInNode, !- Name of the indoor air side heating coil Inlet node
AirOutNod,     !- Name of the indoor air side outlet node
WaterInNod,    !- Name of the water side inlet Node
WateroutNod,   !- Name of the water side outlet node
TankoutNod,    !- Name of a water node for  monitoring the supply water flow amount
ODAirInNod,    !- Name of the outdoor coil air inlet Node
ODAiroutNod,   !- Name of the outdoor coil air outlet node
SCCoil1,    !- Coil object Name of space cooling mode
SHCoil1,    !- Coil object Name of space heating mode
DWHCoil1,   !- Coil object Name of dedicated water heating mode
SCWHCoil1,  !- Coil object Name for SCWH mode
SCDWHCoil1  !- Coil object Name for cooling part of SCDWH mode
SCDWHCoil2  !- Coil object Name for WH part of SCDWH mode
SHDWHCoil1  !- Coil object Name for space heating part of SHDWH mode
SHDWHCoil2  !- Coil object Name for WH part of SHDWH mode
23.0,       !-[C],indoor temperature above which indoor overcooling is allowed
28.0,       !-[C],outdoor temperature above which indoor overcooling is allowed
20.0,       !-[C],indoor temperature above which water heating has the higher priority
16.0,       !-[C],outdoor temperature above which water heating has the higher priority
0,          !-0: match cooling load, 1: match water heating load in SCWH mode
2,          !- minimum speed level for SCWH mode
3.0,        !- [m3], limit of heated water volume before switching from SCDWH to SCWH mode
2,          !- minimum speed level for SCDWH mode
600,        !- [s], time limit before turning on electric element in SHDWH mode
5;          !- minimum speed level for SHDWH mode
```

IDF Objects (Modified):

AirLoopHVAC:UnitarySystem,

```
Sys 1 Var Speed ASHP,    !- Name
FanAndCoilAvailSched,    !- Availability Schedule Name
Sys 1 Mixed Air Node,    !- Air Inlet Node Name
Sys 1 Air Loop Outlet Node,  !- Air Outlet Node Name
1.0,                     !- Supply Air Flow Rate {m3/s}
SPACE1-1,                !- Controlling Zone or Thermostat Location
Fan:OnOff,                           !- Supply Air Fan Object Type
VSASHP Fan 1,            !- Supply Air Fan Name
CoilSystem:IntegratedHeatPump:AirSource,  !- Heating Coil Object Type
ASIHP1,                              !- Heating Coil Name
0.001,                   !- Heating Convergence
CoilSystem:IntegratedHeatPump:AirSource,  !- Cooling Coil Object Type
ASIHP1,                              !- Cooling Coil Name
0.001,                   !- Cooling Convergence
2.5,                     !- Maximum Cycling Rate {cycles/hr}
60,                      !- Heat Pump Time Constant {s}
0.01,                    !- Fraction of On-Cycle Power Use
0,                       !- Heat Pump Fan Delay Time {s}
Coil:Heating:Gas,        !- Supplemental Heating Coil Object Type
VSASHP Supp Htg Coil 1,  !- Supplemental Heating Coil Name
60,                      !- Maximum Supply Air Temperature from Supplemental Heater {C}
20,                      !- Maximum OADB Temperature for Suppl Heater Operation
Sys 1 Outside Air Inlet Node,  !- Outdoor Dry-Bulb Temperature Sensor Node Name
BlowThrough,             !- Fan Placement
FanAndCoilAvailSched,    !- Supply Air Fan Operating Mode Schedule Name
;                        !- Dehumidification Control Type
```

```
WaterHeater:HeatPump:PumpedCondenser,
PlantHeatPumpWaterHeater,!- Name
PlantHPWHSch, !- Availability Schedule Name
PlantHPWHTempSch, !- Compressor Setpoint Temperature Schedule Name
2.0, !- Dead Band Temperature Difference {deltaC}
HPPlantWaterInletNode, !- Condenser Water Inlet Node Name
HPPlantWaterOutletNode, !- Condenser Water Outlet Node Name
0.00115525, !- Condenser Water Flow Rate {m3/s}
1.00695, !- Evaporator Air Flow Rate {m3/s}
OutdoorAirOnly, !- Inlet Air Configuration
, !- Air Inlet Node Name
, !- Air Outlet Node Name
HPPlantAirInletNode, !- Outdoor Air Node Name
HPPlantAirOutletNode, !- Exhaust Air Node Name
, !- Inlet Air Temperature Schedule Name
, !- Inlet Air Humidity Schedule Name
, !- Inlet Air Zone Name
WaterHeater:Mixed, !- Tank Object Type
HPWHPlantTank, !- Tank Name
HPWH Use Inlet Node, !- Tank Use Side Inlet Node Name
HPWH Use Outlet Node, !- Tank Use Side Outlet Node Name
CoilSystem:IntegratedHeatPump:AirSource,  !- Heating Coil Object Type
ASIHP1,                              !- Heating Coil Name
11.0, !- Minimum Inlet Air Temperature for Compressor Operation {C}
Outdoors, !- Compressor Location
, !- Compressor Ambient Temperature Schedule Name
Fan:OnOff, !- Fan Object Type
HPWHPlantFan, !- Fan Name
BlowThrough, !- Fan Placement
, !- On Cycle Parasitic Electric Load {W}
, !- Off Cycle Parasitic Electric Load {W}
; !- Parasitic Heat Rejection Location
```