TYPE 665: AIR SOURCE HEAT PUMP (SPLIT SYSTEM HEAT PUMP)

General Description

Type665 uses a manufacturer's catalog data approach to model an air source heat pump (air flows on both the condenser and evaporator sides of the device. The model includes mixing algorithms and damper settings so that the indoor air may be the result of two streams from different sources (recirculation and makeup air for example. In heating mode, the device is equipped with one of three auxiliary heater types: no auxiliary heat available, two element electric auxiliary heat, or gas fired auxiliary heat. The model is also equipped with a capacity multiplier parameter so that the heat pump may be quickly resized without having to resort to finding new data files.

Nomenclature

$h_{air,FanIn}$	[kJ/hr]	Enthalpy of mixed air entering the indoor fan.
γ_{damper}	[0..1]	Control setting of the damper that determines the fraction of primary and secondary air streams that are mixed together before entering the indoor fan.
$h_{air,primary}$	[kJ/hr]	Enthalpy of the primary (recirculation) air stream
$h_{air,secondary}$	[kJ/hr]	Enthalpy of the secondary (makeup) air stream
$\omega_{air,FanIn}$	[kgH_2O/kgAir]	Humidity ratio of mixed air entering the indoor fan.
$\omega_{air,primary}$	[kgH_2O/kgAir]	Humidity ratio of the primary (recirculation) air stream
$\omega_{air,secondary}$	[kgH_2O/kgAir]	Humidity ratio of the secondary (makeup) air stream
h_{cond}	[kJ/hr]	Enthalpy of condensate resulting from mixing the primary and secondary air streams
$\dot{m}_{cond}$	[kg/hr]	Mass flow rate of condensate resulting from mixing the primary and secondary air streams
$\dot{m}_{air}$	[kg/hr]	Mass flow rate of air
$h_{air,EvapOut}$	[kJ/hr]	Enthalpy of air exiting the evaporator (cooling mode)
$h_{air,EvapIn}$	[kJ/hr]	Enthalpy of air entering the evaporator (cooling mode)
$\dot{Q}_{tot,cool}$	[kJ/hr]	Total cooling power of the heat pump
$\dot{Q}_{sens,cool}$	[kJ/hr]	Sensible cooling power of the heat pump
Cp_{air}	[kJ/kg.K]	Specific heat of air
$T_{Evap,In}$	[ºC]	Temperature of air entering the evaporator (cooling mode)
$T_{EvapOut}$	[ºC]	Temperature of air exiting the evaporator (cooling mode)
$\dot{Q}_{rejection}$	[kJ/hr]	Amount of energy rejected by the heat pump (cooling mode)
$\dot{P}_{comp}$	[kJ/hr]	Compressor power
COP	[-]	Device coefficient of performance
$\dot{P}_{fan,Outdoor}$	[kJ/hr]	Power drawn by the outdoor fan
$\dot{P}_{fan,Indoor}$	[kJ/hr]	Power drawn by the indoor fan
$h_{air,CondenserOut}$	[kJ/hr]	Enthalpy of air exiting the condenser (heating mode)
$h_{air,CondenserIn}$	[kJ/hr]	Enthalpy of air entering the condenser (heating mode)

$\dot{Q}_{tot,heat}$	[kJ/hr]	Total heating power of the heat pump
$\dot{Q}_{absorption}$	[kJ/hr]	Amount of energy absorbed from the outdoor air stream by the heat pump (heating mode)
$\dot{Q}_{aux}$	[kJ/hr]	Auxiliary energy added to the exiting indoor air stream
γ_{aux1}	[0..1]	Control setting on the first stage electric heating element (Auxiliary Mode 1)
$\dot{P}_{aux1}$	[kJ/hr]	Capacity of the first stage electric heating element (Auxiliary Mode 1)
γ_{aux2}	[0..1]	Control setting on the second stage electric heating element (Auxiliary Mode 1)
$\dot{P}_{aux2}$	[kJ/hr]	Capacity of the second stage electric heating element (Auxiliary Mode 1)
η_{aux}	[0..1]	Efficiency of the gas auxiliary heating element (Auxiliary Mode 2)
γ_{aux}	[0..1]	Control setting of the gas auxiliary heating element (Auxiliary Mode 2)
$\dot{P}_{aux}$	[kJ/hr]	Capacity of the gas auxiliary heating element (Auxiliary Mode 2)
T_{cond}	[ºC]	Temperature of condensate exiting the heat pump
$T_{cond,mixing}$	[ºC]	Temperature of condensate resulting from mixing the primary and secondary air streams before entering the indoor fan.
$\dot{m}_{cond,mixing}$	[kg/hr]	Mass flow rate of condensate resulting from mixing the primary and secondary air streams before entering the indoor fan.
$T_{cond,cooling}$	[ºC]	Temperature of condensate resulting from cooling the indoor air stream
$\dot{m}_{cond,cooling}$	[kg/hr]	Mass flow rate of condensate resulting from cooling the indoor air stream
$\dot{m}_{cond}$	[kg/hr]	Total mass flow rate of condensate.

Detailed Description

Air source heat pumps are vapor compression refrigerant devices that are piped and valved in such a way that they can be used in either an air conditioning mode to cool a conditioned space or in a heating mode to heat the same space. The term “air source” simply indicates that air streams pass over both the condenser and evaporator heat exchangers. Heat pumps are either installed as a package unit where the compressor, condenser, expansion valve and evaporator are entirely contained inside one housing. Alternatively, heat pumps may be configured as “split systems” where the condensing heat exchanger and its associated fan are physically separated from the remainder of the system by refrigerant piping. Because Type665 relies on a series of manufacturer’s catalog data files to predict heat pump performance, it can equally well model standard air source heat pumps as well as split system heat pumps. Figure 1 shows a schematic diagram of a heat pump.

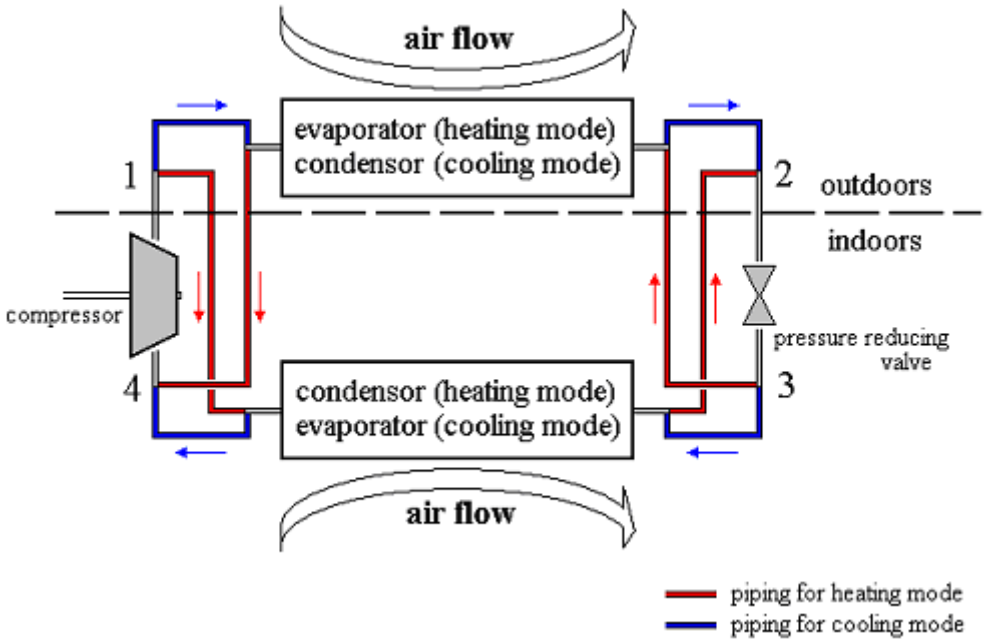


Figure 1: Air Source Heat Pump Schematic

Type665 includes the ability to mix two streams of air on the indoor side of the heat pump through the use of a damper control signal. Normally a fraction of this indoor air stream comes from the conditioned zone and the remainder is made up of outdoor air. However, because the inlet conditions of each of the two streams are defined by the user they can come from any source required by the system.

At any given time step, Type665 first performs an iterative search to determine the properties of the mixed indoor air state. The process begins with a call to the TRNSYS psychrometrics routine in order to obtain those air properties for each inlet air stream not specified by the user among the component's inputs. If dry bulb temperature and humidity ratio are inputs to the model and a humidity ratio higher than the saturation humidity ratio for that dry bulb temperature is specified, the psychrometrics routine will reset the humidity ratio to its saturated condition and print a warning in the TRNSYS list file. Having fully defined the two individual entering air states, Type665 next mixes the two streams according to Equations 665.1a and b.

$$h_{air,FanIn} = \gamma_{damper} h_{air,primary} + (1-\gamma_{damper}) h_{air,secondary} \quad \text{(Eq. 665.1a)}$$

$$\omega_{air,FanIn} = \gamma_{damper} \omega_{air,primary} + (1-\gamma_{damper}) \omega_{air,secondary} \quad \text{(Eq. 665.1b)}$$

The flow rate of the mixed air stream is initially set to the rated value of the indoor air fan set as a parameter to the model. Mixing occurs at the user specified pressure of the primary (indoor) air stream as opposed to the pressure of the secondary (outdoor) air stream. This assumes that the dampers modulate to balance the pressures of the two inlet streams, that the user has provided a damper position that results in the correct flow rates and that the ambient pressure modulates to the inlet pressure. The psychrometrics routine is called once more to determine all properties of the mixed air. Often the procedure of converging on a mixed air state is iterative. Type665 calls PSYCHROMETRICS with pressure, enthalpy and humidity ratio. In return it obtains temperature and modified values of humidity ratio and enthalpy. If the new humidity ratio is lower than the humidity ratio going into the call, the air is determined to have been saturated (PSYCHROMETRICS sets humidity ratio back to the saturation line value if called with saturated conditions). STEAM_PROPS is then called with the new air temperature

to determine the enthalpy of the condensate (condensate is assumed to be at the mixed air temperature) and the enthalpy of the mixed air is calculated using Equation 665.2. If the enthalpy resulting from this calculation is within a tolerance of the mixed air enthalpy returned from the psychrometrics routine, the mixed air state is said to be converged. If the enthalpy difference between 665.2 and PSYCHROMETRICS is not within the tolerance, the air enthalpy is updated to the new value and the procedure begins again. The mixed air state is also deemed to have converged if the procedure has iterated more than 50 times. Both the tolerance on enthalpy and the number of allowable iterations can be modified in the Fortran source code.

$$h_{air,FanIn} = \gamma_{damper} h_{air,primary} + (1-\gamma_{damper}) h_{air,secondary} - h_{cond} \frac{\dot{m}_{cond}}{\dot{m}_{air}} \qquad \text{(Eq. 665.2)}$$

With the mixed air state fully determined, Type665 proceeds to determine whether the heat pump is in heating mode, cooling mode, or whether only the indoor fan is currently in operation. Both cooling performance and heating performance are determined based on catalog data files.

One very important feature of Type665 is the scaling factor (parameter 11). When normalized, many heat pump data files look nearly identical. Consequently it is possible to accurately model a 2 ton heat pump by doubling the heating and cooling power and capacity read from a 1 ton heat pump performance data files.

Cooling Performance Data

Three measures of cooling performance must be provided in the cooling performance data file. These are: total cooling (in kW), sensible cooling (in kW), and power consumed (in kW). The power consumed should include the power associated with the indoor fan, the power associated with the outdoor fan and the power associated with the compressor. The power of the indoor and outdoor fans are also specified among the model's parameters so that the power draw of the compressor can be extracted from the total and so that the power drawn during fan-only operation can be calculated. As with other catalog data performance based components, Type665 linearly interpolates between cooling performance measures based on the current values of the air flow rate (in l/s), mixed return air wet bulb temperature (in ºC), mixed return air dry bulb temperature (in ºC), and outdoor dry bulb temperature (in ºC). It should be noted that the component does not extrapolate beyond the data range provided. If values outside the data range are provided, the maximum or minimum cooling performance values will be returned and a warning will be written to the TRNSYS listing file and to the simulation log file. ?? why is there only one air flow rate are they matched indoor and out? If so, why are there two rated fan powers? Is the assumption that you have enough airflow on the outside??

An example cooling performance data file is provided for use with Type665. The file can be found in ..\Catalog_Data\SSHPs\Sample\Samp_C.dat. Users creating their own performance data must adhere closely to the syntax of the sample file. The values of air flow must all appear on the first row of the data file. The values of mixed return air wet bulb temperature must all appear on the second row of the data file, the values of the mixed return air dry bulb temperature must all appear on the third row of the data file and the values of the outdoor air dry bulb temperature must all appear on the fourth line. Users may specify more or fewer values of each of the four variables than are shown in the sample file but must also remember to modify the corresponding PARAMETERS in the TRNSYS input file. For example, the sample file contains three values of air flow rate. Consequently the value of parameter 9 (number of airflow steps) would be set to 3. The values of all three cooling performance measures must then appear, each group on its own line.

After having queried the TRNSYS DYNAMICDATA subroutine for the cooling performance data for the current conditions, checks are made in the code to ensure that the catalog data is reasonable. If, for example, the sensible cooling power returned is higher than the total cooling power, the total cooling power is increased to match the sensible value. While this may seem counter intuitive, it is an industry standard when dealing with this situation in catalog data. The state of the air exiting the cooling mode evaporator is determined by equation 665.3.

$$h_{air,EvapOut} = h_{air,EvapIn} - \frac{\dot{Q}_{tot,cool}}{\dot{m}_{air}} \quad \text{(Eq. 665.3)}$$

PSYCHROMETRICS is called to determine the remaining properties. The pressure rise across the indoor fan is applied to the air at this point in the calculations. Again, the enthalpy of the exiting air may be modified by the PSYCHROMETRICS. The total cooling heat transfer is recalculated based on the enthalpy difference between entering and exiting evaporator air conditions. The sensible cooling is calculated based on the temperature difference as defined in Equation 665.4.

$$\dot{Q}_{sens,cool} = \dot{m}_{air} Cp_{air} \left(T_{Evap,In} - T_{EvapOut} \right) \quad \text{(Eq. 665.4)}$$

The latent cooling is computed as the difference between the total and the sensible cooling values. At this point the rated power of the indoor and outdoor fans supplied as parameters are removed from the total power returned from the data file so as to arrive at the power of the compressor, which enters into the calculation of the rejection energy as defined in equation 665.5.

$$\dot{Q}_{rejection} = \dot{Q}_{tot,cool} + \dot{P}_{comp} \quad \text{(Eq. 665.5)}$$

The COP of the heat pump in cooling is defined by equation 665.6

$$COP = \frac{\dot{Q}_{tot,cool}}{\dot{P}_{comp} + \dot{P}_{fan,Outdoor} + \dot{P}_{fan,Indoor}} \quad \text{(Eq. 665.6)}$$

Heating Performance Data

The specification of heating performance data is much the same as for cooling performance data. Two measures of heating performance must be provided in the heating performance data file. These are: total heating (in kW), and power consumed (in kW). As with the cooling data file, the power consumed should include the power associated with the indoor and outdoor fans as well as the power associated with the compressor. Type665 linearly interpolates between heating performance measures based on the current values of the air flow rate (in l/s), indoor air dry bulb temperature (in ºC) and outdoor dry bulb temperature (in ºC). It should be noted that the component does not extrapolate beyond the data range provided. If values outside the data range are provided, the maximum or minimum cooling performance values will be returned and a warning will be written to the TRNSYS listing file and to the simulation log file.

An example heating performance data file is provided for use with Type665. The file can be found in ..\Catalog_Data\SSHPs\Sample\Samp_H.dat. Users creating their own performance data must adhere

closely to the syntax of the sample file. The values of air flow must all appear on the first row of the data file. The values of indoor air dry bulb temperature must all appear on the second row of the data file, and the values of the outdoor air dry bulb temperature must all appear on the third row of the data file. Users may specify more or fewer values of each of the three variables than are shown in the sample file but must also remember to modify the corresponding PARAMETER in the TRNSYS input file. For example, the sample file contains three values of air flow rate. Consequently the value of the parameter 9 (number of airflow steps) would be set to 3. The values of both heating performance measures must then appear, each group on its own line.

With heating performance known, the state of the air exiting the condenser is calculated based on enthalpy with air pressure increased to account for pressure rise across the fan.

$$h_{air,CondenserOut} = h_{air,CondenserIn} + \frac{\dot{Q}_{tot,heat}}{\dot{m}_{air}} \qquad \text{(Eq. 665.7)}$$

As was the case in cooling, PSYCHROMETRICS is called to completely define the air state, possibly resulting in a modified enthalpy. Heating power is recalculated as the mass flow rate of air multiplied by the enthalpy difference between the air inlet and outlet state. The energy absorbed ?? and the appliance COP are computed based on equations 665.8 and 665.9.

$$\dot{Q}_{absorption} = \dot{Q}_{tot,heat} - \dot{P}_{comp} \qquad \text{(Eq. 665.8)}$$

$$COP = \frac{\dot{Q}_{tot,heat}}{\dot{P}_{comp} + \dot{P}_{fan,Outdoor} + \dot{P}_{fan,Indoor}} \qquad \text{(Eq. 665.9)}$$

Fan Only Operation

The air source heat pump can also operate in a mode where neither active cooling nor active heating is required but the indoor fan is on to continue circulating air or mixing return air with outdoor air. In this mode, only mixing with the secondary air stream, indoor fan inefficiencies and associated pressure rise affect the state of the air returned to the space.

Auxiliary Heat

Type665 is equipped with the ability to add auxiliary energy to the post condenser (in heating mode) or post evaporator (in cooling mode) indoor air stream by one of three methods: no auxiliary heat available, two element staged electric auxiliary heat available, or gas fired auxiliary heat available. In both cases, the amount of auxiliary energy added is determined by the value of the auxiliary heat control signals (inputs to the model) and by the capacity of the heaters in question. Note that because the control signals are all separate, auxiliary heat may be added to the exiting indoor air stream both in cooling and in heating mode. This feature allows the heat pump to be operated in a dehumidification mode that passes air across a cooling coil and then reheats it before returning it to the conditioned space.

In auxiliary mode 0, no auxiliary heat is available and the air exits the device at the conditions at which it left the condenser in heating mode or the evaporator in cooling mode. Auxiliary mode 1 models a two stage electric heat auxiliary. The amount of auxiliary energy added to the exiting indoor air stream is given by equation 665.10

$$\dot{Q}_{aux} = \gamma_{aux1}\dot{P}_{aux1} + \gamma_{aux2}\dot{P}_{aux2} \quad \text{(Eq. 665.10)}$$

Outlet air state is computed through the standard call to the PSYCHROMETRICS routine and COP is calculated based on equation 665.11

$$COP = \frac{\dot{Q}_{tot,heat}}{\dot{P}_{comp} + \dot{P}_{fan,Outdoor} + \dot{P}_{fan,Indoor} + \dot{Q}_{aux}} \quad \text{(Eq. 665.11)}$$

In auxiliary mode 2 (gas fired auxiliary), the amount of auxiliary energy added to the exiting indoor air stream is based on the burner capacity, control signal and efficiency as shown in 665.12.

$$\dot{Q}_{aux} = \eta_{aux}\gamma_{aux}\dot{P}_{aux} \quad \text{(Eq. 665.12)}$$

The corresponding COP is calculated in the same manner as it was for auxiliary mode 1. If any condensate resulted from either mixing the primary and secondary air streams or through cooling, the total flow rate of condensate is determined. The temperature of the out flowing condensate is set as shown in equation 665.13.

$$T_{cond} = \frac{T_{cond,mixing}\dot{m}_{cond,mixing} + T_{cond,cooling}\dot{m}_{cond,cooling}}{\dot{m}_{cond}} \quad \text{(Eq. 665.13)}$$