### ZoneHVAC:LowTemperatureRadiant:VariableFlow

This low temperature radiant system (hydronic) is a component of zone equipment that is intended to model any “radiant system” where water is used to supply/remove energy to/from a building surface (wall, ceiling, or floor). The component is controlled to meet any remaining zone load not met by other equipment in the zone that have higher priority. The control is accomplished by throttling the hot or chilled water flow to the unit. Note that this system will only control based on the radiant system controls defined by this input syntax and not via a zone thermostat such as is used for forced air systems. Note also that because this unit does not require a thermostat that in cases where no other systems are serving the zone in which this system resides that it will use the heating equipment priority to determine which system will run first. If the radiant system is serving a zone with forced air equipment, the radiant system will follow the priority order established by the zone thermostat but will still base its response on the controls defined by the user for the radiant system.

This model covers a wide range of low temperature radiant systems: heating and/or cooling, panel or embedded pipes, etc. It is not intended to simulate high temperature electric or gas radiant heaters. Those devices will be handled by a separate model and different input syntax. Low temperature radiant systems that use electric resistance heating should also be defined using separate input syntax (ref: ZoneHVAC:LowTemperatureRadiant:Electric).

#### Field: Name

This field is an unique user assigned name for an instance of a hydronic low temperature radiant system. Any reference to this unit by another object will use this name.

#### Field: Availability Schedule Name

This field is the name of the schedule (ref: Schedule) that denotes whether the hydronic low temperature radiant system can run during a given time period. A schedule value less than or equal to 0 (usually 0 is used) denotes that the unit must be off for that time period. A value greater than 0 (usually 1 is used) denotes that the unit is available to operate during that time period. If this field is left blank, the schedule has a value of 1 for all time periods.

#### Field: Zone Name

This field is the name of the zone (Ref: Zone) in which the hydronic low temperature radiant system is principally located and intended to affect. A system that is between two zones will still act upon each zone; however, the zone name referenced here should be the zone that controls the radiant system response.

#### Field: Surface Name or Radiant Surface Group Name

This field is the name of the surface (Ref: BuildingSurface) or surface list (Ref: ZoneHVAC:LowTemperatureRadiant:SurfaceGroup) in which the hydronic tubing is embedded/contained. This specification attaches the source or sink from the radiant system to a particular surface and the contribution of the system to the heat balances of that surface. If this field is a surface list, then the source or sink is attached to all of the surfaces in the list with the radiant system surface group defining the breakdown of how flow rate is split between the various surfaces. Base surfaces (e.g., BuildingSurface:Detailed), door surfaces and internal mass are valid. Window surfaces are not valid surface types for embedded radiant systems.

#### Field: Hydronic Tubing Inside Diameter

This field is the inside diameter of the tubes through which water is circulated for the system being defined by this statement. The inside diameter should be recorded in meters and is used to determine the convective heat transfer from the water to the inside surface of the hydronic tubing.

#### Field: Hydronic Tubing Length

This field is the total length of pipe embedded in the surface named above in the surface name field. The length of the tube should be entered in meters and is used to determine the effectiveness of heat transfer from the fluid being circulated through the tubes and the tube/surface. Longer tubing lengths result in more heat will be transferred to/from the radiant surface to the circulating fluid. Note that if the user elects to autosize this field that a standard zone thermostat such as would be used for a forced air system must be defined as autosizing calculations are based on the zone thermostat value and not on the radiant system control values.

#### Field: Temperature Control Type

This field specifies along with the throttling range and setpoint schedules how the user wishes to control the hydronic radiant system. The temperature denoted in the setpoint schedule can refer to one of five different temperatures: the zone mean air temperature, the zone mean radiant temperature, the zone operative temperature, the outdoor dry-bulb temperature, or the outdoor wet-bulb temperature. The choice of temperature is controlled by the current field—temperature control type. The user must select from the following options:

MeanAirTemperature

MeanRadiantTemperature

OperativeTemperature

OutdoorDryBulbTemperature

OutdoorWetBulbTemperature

Operative temperature for radiant system controls is the average of Mean Air Temperature and Mean Radiant Temperature. If the user does not select a control type, **MeanAirTemperature** control is assumed by EnergyPlus. See the throttling range and control temperature schedule fields below for more information.

#### Field: Heating Design Capacity Method

Enter the method used to determine the heating design capacity for scalable sizing. Input allowed is either *HeatingDesignCapacity*, *CapacityPerFloorArea*, and *FractionOfAutosizedHeatingCapacity*. If this input field is left blank or zero, then autosizing is assumed. *HeatingDesignCapacity* means user specifies the magnitude of maximum or nominal heating capacity or the program calculates the design heating capacity if autosize is specified. *CapacityPerFloorArea* means the program calculates the design heating capacity from user specified heating capacity per floor area and floor area of the zone served by the low temperature radiant variable flow unit. *FractionOfAutosizedHeatingCapacity* means the program calculates the design heating capacity from user specified fraction and the auto-sized design heating capacity. The default method is *HeatingDesignCapacity*.

#### Field: Heating Design Capacity {W}

This field is for the low temperature radiant variable flow unit design heating capacity in watts. This field can be autosized by EnergyPlus. This input field is autosizable. When the Heating Design Capacity Method is *HeatingDesignCapacity* and this input is is blank, autosizing is assumed. Design day sizing run must be specified if autosized.

#### Field: Heating Design Capacity Per Floor Area {W/m2}

Enter the heating capacity per unit floor area in m3/s-m2 of low temperature radiant variable flow unit. This field is required field when the Heating Design Capacity Method is *CapacityPerFloorArea*. The program calculates the heating capacity from floor area of the zone served by the low temperature radiant variable flow unit and the heating capacity per unit floor area value specified by the user. This field may be left blank.

#### Field: Fraction of Autosized Heating Design Capacity {-}

Enter the heating capacity as a fraction of the autosized heating capacity for low temperature radiant variable flow unit. This input field is required when the Heating Design Capacity Method is *FractionOfAutosizedHeatingCapacity*. The program calculates the heating capacity from the design autosized heat capacity and user specified fraction. Design day sizing run must be specified. This field may be left blank. Default value is 1.0.

#### Field: Maximum Hot Water Flow

This field is the maximum flow rate of hot water through the radiant system in m3/sec. The controls for the radiant system will vary the flow rate of hot water through the surface using zero flow and the maximum flow rate specified in this field as the lower and upper bounds, respectively. Note that if the user elects to autosize this field that a standard zone thermostat such as would be used for a forced air system must be defined as autosizing calculations are based on the zone thermostat value and not on the radiant system control values.

#### Field: Heating Water Inlet Node Name

This field contains the name of the hot water inlet node to the radiant system. Note that this node name must also show up in the branch description when defining the plant demand side network in a manner identical to defining a heating coil.

#### Field: Heating Water Outlet Node Name

This field contains the name of the hot water oulet node to the radiant system. Note that this node name must also show up in the branch description when defining the plant demand side network in a manner identical to defining a heating coil.

#### Field: Heating Control Throttling Range

This field specifies the range of temperature in degrees Celsuis over which the radiant system throttles from zero flow rate up to the maximum defined by the maximum hot water flow rate field described above. The throttling range parameter is used in conjunction with the control temperature to define the response of the system to various zone conditions. The heating control temperature schedule specifies the “setpoint” temperature where the flow rate to the system is at half of the maximum flow rate. For example, if the heating control temperature setpoint is currently 15°C and the heating throttling range is 2°C, the water flow rate to the radiant system will be zero when the controlling temperature (MAT, MRT, Operative Temperature, ODB, or OWB; see control type field above) is at or above 16°C and the maximum flow rate when the controlling temperature is at or below 14°C. This represents a throttling range of 2°C around the setpoint of 15°C. In between 14°C and 16°C, the flow rate to the radiant system is varied linearly.

#### Field: Heating Control Temperature Schedule Name

This field specifies the heating setpoint or control temperature for the radiant system in degrees Celsius. Used in conjunction with the previous field (heating control throttling range), it will define whether or not the system is running and the current flow rate. Water flow rate to the system is varied linearly around the setpoint temperature based on the throttling range and the maximum heating flow rate parameters (see above). It should be noted that this control schedule will allow different setpoint temperatures throughout the year for heating. The control of the radiant system is based solely on the heating control temperature schedule, the cooling control temperature schedule (see below), and the control temperature type listed above. The radiant system will not use any zone thermostat that might be used by other systems serving the zone in which the radiant system resides.

#### Field: Cooling Design Capacity Method

Enter the method used to determine the cooling design capacity for scalable sizing. Input allowed is either *CoolingDesignCapacity*, *CapacityPerFloorArea*, and *FractionOfAutosizedCoolingCapacity*. If this input field is left blank or zero, then autosizing is assumed. *CoolingDesignCapacity* means user specifies the design cooling capacity or the program calculates the design cooling capacity if autosize is specified. *CapacityPerFloorArea* means the program calculates the design cooling capacity from user specified heating capacity per floor area and floor area of the zone served by the low temperature radiant variable flow unit. *FractionOfAutosizedCoolingCapacity* means the program calculates the design cooling capacity from user specified fraction and the auto-sized design cooling capacity. The default method is *CoolingDesignCapacity*.

#### Field: Cooling Design Capacity {W}

This field is for the low temperature radiant variable flow unit design cooling capacity in watts. This field can be autosized by EnergyPlus. This input field is autosizable. When the Cooling Design Capacity Method is *CoolingDesignCapacity* and this input is is blank, autosizing is assumed. Design day sizing run must be specified if autosized.

#### Field: Cooling Design Capacity Per Floor Area {W/m2}

Enter the cooling capacity per unit floor area in m3/s-m2 of low temperature radiant variable flow unit. This field is required field when the Cooling Design Capacity Method is *CapacityPerFloorArea*. The program calculates the cooling capacity from floor area of the zone served by the low temperature radiant variable flow unit and the cooling capacity per unit floor area value specified by the user. This field may be left blank.

#### Field: Fraction of Autosized Cooling Design Capacity {-}

Enter the cooling capacity as a fraction of the autosized cooling capacity for low temperature radiant variable flow unit. This input field is required when the Cooling Design Capacity Method is *FractionOfAutosizedCoolingCapacity*. The program calculates the cooling capacity from the design autosized cooling capacity and user specified fraction. Design day sizing run must be specified. This field may be left blank. Default value is 1.0.

#### Field: Maximum Cold Water Flow

This field is the maximum flow rate of cold water through the radiant system in m3/sec. The controls for the radiant system will vary the flow rate of cold water through the surface using zero flow and the maximum flow rate specified in this field as the lower and upper bounds, respectively. Note that this field is optional and not required for a heating only system. Note also that if the user elects to autosize this field that a standard zone thermostat such as would be used for a forced air system must be defined as autosizing calculations are based on the zone thermostat value and not on the radiant system control values.

#### Field: Cooling Water Inlet Node Name

This field contains the name of the cold water inlet node to the radiant system. Note that this node name must also show up in the branch description when defining the plant demand side network in a manner identical to defining a cooling coil. As with the maximum cold water flow rate, this field is optional and not required for a heating only system.

#### Field: Cooling Water Outlet Node Name

This field contains the name of the cold water oulet node to the radiant system. Note that this node name must also show up in the branch description when defining the plant demand side network in a manner identical to defining a cooling coil. As with the maximum cold water flow rate, this field is optional and not required for a heating only system.

#### Field: Cooling Control Throttling Range

This field specifies the range of temperature in degrees Celsuis over which the radiant system throttles from zero flow rate up to the maximum defined by the maximum cold water flow rate field described above. The throttling range parameter is used in conjunction with the control temperature to define the response of the system to various zone conditions. The cooling control temperature schedule specifies the “setpoint” temperature where the flow rate to the system is at half of the maximum flow rate. For example, if the cooling control temperature setpoint is currently 25°C and the cooling throttling range is 2°C, the water flow rate to the radiant system will be zero when the controlling temperature (MAT, MRT, Operative Temperature, ODB, or OWB; see control type field above) is at or below 24°C and the maximum flow rate when the controlling temperature is at or above 26C. This represents a throttling range of 2°C around the setpoint of 25°C. In between 24°C and 26°C, the flow rate to the radiant system is varied linearly.

#### Field: Cooling Control Temperature Schedule Name

This field specifies the cooling setpoint or control temperature for the radiant system in degrees Celsius. Used in conjunction with the previous field (cooling control throttling range), it will define whether or not the system is running and the current flow rate. Water flow rate to the system is varied linearly around the setpoint temperature based on the throttling range and the maximum cooling flow rate parameters (see above). It should be noted that this control schedule will allow different setpoint temperatures throughout the year for cooling. The control of the radiant system is based solely on the heating control temperature schedule listed above, the cooling control temperature schedule, and the control temperature type listed above. The radiant system will not use any zone thermostat that might be used by other systems serving the zone in which the radiant system resides.

#### Field: Condensation Control Type

When radiant systems do cooling, there is the possibility that condensation will occur on the surface that is being cooled. This is due to the fact that the surface temperature may drop below the dew-point temperature of the space. When this occurs, condensation on the surface will occur. In EnergyPlus, users have several options for handling this situation including: Off and SimpleOff. When the user chooses the Off option, EnergyPlus will not do anything other than produce a warning message when condensation is predicted to occur. The program will simply continue on; no moisture will be removed from the zone air and there will be no adjustment of the surface temperature as a result of the condensation. When the user chooses the SimpleOff option, the program will predict cases where condensation will occur and shut-off the radiant system to avoid this situation. With this option, the users also have the opportunity to adjust when the system will shut down. This is specified with the next parameter (field: condensation differential parameter). This parameter is optional and EnergyPlus will use the SimpleOff strategy when this parameter is not specified.

#### Field: Condensation Control Dewpoint Offset

This optional parameter is only valid with the SimpleOff condensation handling algorithm (see previous input parameter). It establishes the difference between the calculated dew-point temperature of the space and the allowed surface temperature to which the surface can drop before the radiant system shuts down in degrees Celsius. This parameter can be any positive, negative, or zero value. When this parameter is zero, the radiant system will shut down when the surface temperature drops to the dew-point temperature or below. When this parameter is positive, the radiant system will shut down when the surface is the number of degrees Celsius above the dew-point temperature. This allows some extra safety to avoid condensation. When this parameter is negative, the radiant system will shut down when the surface temperature is the number of degrees Celsius below the dew-point temperature. While not recommended, this strategy allows the user to simulate a situation where small amounts of condensation are tolerable.

#### Field: Number of Circuits

This optional input allows the user to choose between modeling each surface in the radiant system as a single hydronic circuit or to allow the program to divide the surface into multiple parallel hydronic circuits based on the next input field *Circuit Length*. To model as a single circuit choose *OnePerSurface*. To model as multiple circuits choose *CalculateFromCircuitLength*. It is recommended that *CalculateFromCircuitLength* be chosen. The default is *OnePerSurface* for backward compatibility with older versions of EnergyPlus.

#### Field: Circuit Length

The length in meters of each parallel hydronic circuit in a surface. Used when the previous input field is set to *CalculateFromCircuitLength*. The default is 106.7 meters (350 feet), which is the maximum circuit length allowed in Title 24.

An example IDF with a hydronic low temperature radiant system is shown below.

ZoneHVAC:LowTemperatureRadiant:VariableFlow,

SPACE1-1 Zone Radiant Floor, !- Name

RADIANTSYSAVAILSCHED, !- Availability Schedule Name

SPACE1-1, !- Zone Name

C1-1, !- Surface Name or Radiant Surface Group Name

0.013, !- Hydronic Tubing Inside Diameter {m}

autosize, !- Hydronic Tubing Length {m}

OperativeTemperature, !- Temperature Control Type

HeatingDesignCapacity, !- Heating Design Capacity Method

autosize, !- Heating Design Capacity{ W }

, !- Heating Design Capacity Per Floor Area{ W / m2 }

, !- Fraction of Autosized Heating Design Capacity{ -}

0.0004, !- Maximum Hot Water Flow {m3/s}

SPACE1-1 Zone Radiant Water Inlet Node, !- Heating Water Inlet Node Name

SPACE1-1 Zone Radiant Water Outlet Node, !- Heating Water Outlet Node Name

2.0, !- Heating Control Throttling Range {deltaC}

RADIANT HEATING SETPOINTS, !- Heating Control Temperature Schedule Name

CoolingDesignCapacity, !- Cooling Design Capacity Method

autosize, !- Cooling Design Capacity{ W }

, !- Cooling Design Capacity Per Floor Area{ W / m2 }

, !- Fraction of Autosized Cooling Design Capacity{ -}

autosize, !- Maximum Cold Water Flow {m3/s}

SPACE1-1 Cooling Water Inlet Node, !- Cooling Water Inlet Node Name

SPACE1-1 Cooling Water Outlet Node, !- Cooling Water Outlet Node Name

2.0, !- Cooling Control Throttling Range {deltaC}

RADIANT COOLING SETPOINTS, !- Cooling Control Temperature Schedule Name

Off, !- Condensation Control Type

1.0, !- Condensation Control Dewpoint Offset

CalculateFromCircuitLength, !- Number of Circuits

106.7; !- Circuit Length

### Low Temperature Radiant Variable Flow (ZoneHVAC) Outputs

HVAC,Average,Zone Radiant HVAC Heating Rate [W]

HVAC,Sum,Zone Radiant HVAC Heating Energy [J]

HVAC,Average,Zone Radiant HVAC Cooling Rate [W]

HVAC,Sum,Zone Radiant HVAC Cooling Energy [J]

HVAC,Average,Zone Radiant HVAC Mass Flow Rate [kg/s]

HVAC,Average,Zone Radiant HVAC Inlet Temperature [C]

HVAC,Average,Zone Radiant HVAC Outlet Temperature [C]

HVAC,Sum,Zone Radiant HVAC Moisture Condensation Time[s]

HVAC,Sum,Zone Radiant HVAC Heating Fluid Energy [J]

HVAC,Sum,Zone Radiant HVAC Cooling Fluid Energy [J]

#### Zone Radiant HVAC Heating Rate [W]

This field reports the heating input rate to the low temperature radiant system in Watts. This is the heat source to the surface that is defined as the radiant system. The heating rate is determined by the zone conditions and the control scheme defined in the user input.

#### Zone Radiant HVAC Heating Energy [J]

This field reports the heating input to the low temperature radiant system in Joules. This is the heat source to the surface that is defined as the radiant system. The heating rate is determined by the zone conditions, the control scheme defined in the user input, and the timestep.

#### Zone Radiant HVAC Cooling Rate [W]

This field reports the cooling input rate to the low temperature radiant system in Watts. This is the heat sink to the surface that is defined as the radiant system. The cooling rate is determined by the zone conditions and the control scheme defined in the user input.

#### Zone Radiant HVAC Cooling Energy [J]

This field reports the cooling input to the low temperature radiant system in Joules. This is the heat sink to the surface that is defined as the radiant system. The cooling rate is determined by the zone conditions, the control scheme defined in the user input, and the timestep.

#### Zone Radiant HVAC Mass Flow Rate Rate [kg/s]

This field reports the mass flow rate of water through the low temperature radiant system in kilograms per second.

#### Zone Radiant HVAC Inlet Temperature [C]

This field reports the temperature of water entering the low temperature radiant system in Celsius.

#### Zone Radiant HVAC Outlet Temperature [C]

This field reports the temperature of water leaving the low temperature radiant system in Celsius.

#### Zone Radiant HVAC Moisture Condensation Time[s]

This field reports the amount of time when condensation is occurring. When using the Off condensation control, this simply reports the amount of time when condensation occurs. When using the SimpleOff condensation control, this indicates the amount of time when the system has been shut off because of the potential danger of condensation.

#### Zone Radiant HVAC Heating Fluid Energy [J]

This is the demand placed on the hot fluid plant loop connection serving the low temperature radiant system, in Joules.

#### Zone Radiant HVAC Cooling Fluid Energy [J]

This is the demand placed on the cooling fluid plant loop connection serving the low temperature radiant system, in Joules.

### ZoneHVAC:LowTemperatureRadiant:ConstantFlow

This low temperature radiant system (hydronic) is a component of zone equipment that is intended to model any “radiant system” where water is used to supply/remove energy to/from a building surface (wall, ceiling, or floor). The component is controlled via control schedules as described in the syntax below and does not require a zone thermostat. Note that because this unit does not require a thermostat that in cases where no other systems are serving the zone in which this system resides that it will use the heating equipment priority to determine which system will run first. If the radiant system is serving a zone with forced air equipment, the radiant system will follow the priority order established by the zone thermostat but will still base its response on the controls defined by the user for the radiant system.

The constant flow system differs from the hydronic system describe above in what it controls. The hydronic system varies the flow rate through the radiant system based on some control temperature. The constant flow system keeps flow rate constant via a local circulation pump and varies the water temperature that is sent to the radiant system. This is accomplished with a mixing valve that is controlled by a sensor. This model covers a wide range of low temperature radiant systems: heating and/or cooling, panel or embedded pipes, etc. It is not intended to simulate high temperature electric or gas radiant heaters. Those devices will be handled by a separate model and different input syntax. Low temperature radiant systems that use electric resistance heating should also be defined using separate input syntax (ref: ZoneHVAC:LowTemperatureRadiant:Electric). Low temperature radiant systems that vary the flow rate through the radiant system should also be defined using separate input syntax (ref: ZoneHVAC:LowTemperatureRadiant:VariableFlow)

One of the other differences between this model and the variable flow hydronic radiant system is that the constant flow radiant system has a built-in local secondary loop. It will recirculate flow coming out of the system and mix this with flow from the loop to arrive at the desired inlet temperature to the radiant system (note that this model has the temperature sensor AFTER the pump to insure proper inlet temperature to the radiant system). The local loop also contains a pump which is assumed to be upstream of the radiant system and after the mixing valve. So, the local loop can have some recirculation. The flow from the main loop may also bypass the radiant system if more than enough flow is available and the main loop is also a constant flow system.

#### Field: Name

This field is an unique user assigned name for an instance of a constant flow low temperature radiant system. Any reference to this unit by another object will use this name.

#### Field: Availability Schedule Name

This field is the name of the schedule (ref: Schedule) that denotes whether the constant flow low temperature radiant system can run during a given time period. A schedule value less than or equal to 0 (usually 0 is used) denotes that the unit must be off for that time period. A value greater than 0 (usually 1 is used) denotes that the unit is available to operate during that time period. If this field is left blank, the schedule has a value of 1 for all time periods.

#### Field: Zone Name

This field is the name of the zone (Ref: Zone) in which the constant flow low temperature radiant system is principally located and intended to affect. A system that is between two zones will still act upon each zone; however, the zone name referenced here should be the zone that controls the radiant system response.

#### Field: Surface Name or Radiant Surface Group Name

This field is the name of the surface (Ref: BuildingSurface:Detailed) or surface list (Ref: ZoneHVAC:LowTemperatureRadiant:SurfaceGroup) in which the hydronic tubing is embedded/contained. This specification attaches the source or sink from the radiant system to a particular surface and the contribution of the system to the heat balances of that surface. If this field is a surface list, then the source or sink is attached to all of the surfaces in the list with the radiant system surface group defining the breakdown of how flow rate is split between the various surfaces. Base surfaces (e.g., BuildingSurface:Detailed), door surfaces and internal mass are valid. Window surfaces are not valid surface types for embedded radiant systems.

#### Field: Hydronic Tubing Inside Diameter

This field is the inside diameter of the tubes through which water is circulated for the system being defined by this statement. The inside diameter should be recorded in meters and is used to determine the convective heat transfer from the water to the inside surface of the hydronic tubing.

#### Field: Hydronic Tubing Length

This field is the total length of pipe embedded in the surface named above in the surface name field. The length of the tube should be entered in meters and is used to determine the effectiveness of heat transfer from the fluid being circulated through the tubes and the tube/surface. Longer tubing lengths result in more heat being transferred to/from the radiant surface to the circulating fluid. This field is autosizable.

#### Field: Temperature Control Type

This field specifies along with setpoint (control) and water schedules how the user wishes to control the constant flow radiant system. The temperature denoted in the setpoint schedule can refer to one of five different temperatures: the zone mean air temperature, the zone mean radiant temperature, the zone operative temperature, the outdoor dry-bulb temperature, or the outdoor wet-bulb temperature. The choice of temperature is controlled by the current field—temperature control type. The user must select from the following options:

MeanAirTemperature

MeanRadiantTemperature

OperativeTemperature

OutdoorDryBulbTemperature

OutdoorWetBulbTemperature

Operative temperature for radiant system controls is the average of Mean Air Temperature and Mean Radiant Temperature. If the user does not select a control type, **MeanAirTemperature** control is assumed by EnergyPlus. See the throttling range and control temperature schedule fields below for more information.

#### Field: Rated Flow Rate

This field is the maximum flow rate of water through the radiant system in m3/sec. This flow rate is held constant by the local component pump, but the user has the option of varying this flow rate via a schedule (see next input field). The constant flow system will accept this flow rate and control the inlet temperature based on the control and water temperature schedules defined below. This field is autosizable.

#### Field: Pump Flow Rate Schedule Name

This field modifies the maximum flow rate of water through the radiant system in m3/sec. This input is “optional”. If the user does not enter a schedule, the flow rate through the radiant system is assumed to be constant during all hours that it is operating based on the value entered in the previous input field. Note that the values for this schedule must be between zero and one. The values in this schedule are multipliers on the previous field – Rated Flow Rate.

#### Field: Rated Pump Head

This numeric field contains the pump’s rated head in Pascals.

#### Field: Rated Power Consumption

This numeric field contains the pump’s rated power consumption in Watts.

#### Field: Motor Efficiency

This numeric field contains the pump’s efficiency in decimal form (0 = 0%, 1 = 100%).

#### Field: Fraction of Motor Inefficiencies to Fluid Stream

This numeric field contains the pump’s fraction of power loss to the fluid.

#### Field: Heating Water Inlet Node Name

This field contains the name of the hot water inlet node to the radiant system. Note that this node name must also show up in the branch description when defining the plant demand side network in a manner identical to defining a heating coil.

#### Field: Heating Water Outlet Node Name

This field contains the name of the hot water outlet node to the radiant system. Note that this node name must also show up in the branch description when defining the plant demand side network in a manner identical to defining a heating coil.

#### Field: Heating High Water Temperature Schedule Name

This field specifies the high water temperature in degrees Celsius for the temperature control of a constant flow radiant heating system. Water and control temperatures for heating work together to provide a linear function that determines the water temperature sent to the radiant system. The current control temperature (see Temperature Control Type above) is compared to the high and low control temperatures at the current time. If the control temperature is above the high temperature, then the system will be turned off and the water mass flow rate will be zero. If the control temperature is below the low temperature, then the inlet water temperature is set to the high water temperature. If the control temperature is between the high and low value, then the inlet water temperature is linearly interpolated between the low and high water temperature values. For more information and a graph of how the water and control schedules affect the system operation, please consult the Engineering Reference document.

#### Field: Heating Low Water Temperature Schedule Name

This field specifies the low water temperature in degrees Celsius for the temperature control of a constant flow heating radiant system. For more information on its interpretation, see Heating High Water Temperature Schedule above.

#### Field: Heating High Control Temperature Schedule Name

This field specifies the high control temperature in degrees Celsius for the temperature control of a constant flow heating radiant system. For more information on its interpretation, see Heating High Water Temperature Schedule above.

#### Field: Heating Low Control Temperature Schedule Name

This field specifies the low control temperature in degrees Celsius for the temperature control of a constant flow heating radiant system. For more information on its interpretation, see Heating High Water Temperature Schedule above.

#### Field: Cooling Water Inlet Node Name

This field contains the name of the cold water inlet node to the radiant system. Note that this node name must also show up in the branch description when defining the plant demand side network in a manner identical to defining a cooling coil. As with the maximum cold water flow rate, this field is optional and not required for a heating only system.

#### Field: Cooling Water Outlet Node Name

This field contains the name of the cold water outlet node to the radiant system. Note that this node name must also show up in the branch description when defining the plant demand side network in a manner identical to defining a cooling coil. As with the maximum cold water flow rate, this field is optional and not required for a heating only system.

#### Field: Cooling High Water Temperature Schedule Name

This field specifies the high water temperature in degrees Celsius for the temperature control of a constant flow radiant cooling system. Water and control temperatures for heating work together to provide a linear function that determines the water temperature sent to the radiant system. The current control temperature (see Temperature Control Type above) is compared to the high and low control temperatures at the current time. If the control temperature is above the high temperature, then the inlet water temperature is set to the low water temperature. If the control temperature is below the low temperature, then system will be turned off and the water mass flow rate will be zero. If the control temperature is between the high and low value, then the inlet water temperature is linearly interpolated between the low and high water temperature values. For more information and a graph of how the water and control schedules affect the system operation, please consult the Engineering Reference document.

#### Field: Cooling Low Water Temperature Schedule Name

This field specifies the low water temperature in degrees Celsius for the temperature control of a constant flow cooling radiant system. For more information on its interpretation, see Cooling High Water Temperature Schedule above.

#### Field: Cooling High Control Temperature Schedule Name

This field specifies the high control temperature in degrees Celsius for the temperature control of a constant flow cooling radiant system. For more information on its interpretation, see Cooling High Water Temperature Schedule above.

#### Field: Cooling Low Control Temperature Schedule Name

This field specifies the low control temperature in degrees Celsius for the temperature control of a constant flow cooling radiant system. For more information on its interpretation, see Cooling High Water Temperature Schedule above.

#### Field: Condensation Control Type

When radiant systems do cooling, there is the possibility that condensation will occur on the surface that is being cooled. This is due to the fact that the surface temperature may drop below the dew-point temperature of the space. When this occurs, condensation on the surface will occur. In EnergyPlus, users have several options for handling this situation including: Off and SimpleOff. When the user chooses the Off option, EnergyPlus will not do anything other than produce a warning message when condensation is predicted to occur. The program will simply continue on; no moisture will be removed from the zone air and there will be no adjustment of the surface temperature as a result of the condensation. When the user chooses the SimpleOff option, the program will predict cases where condensation will occur and shut-off the radiant system to avoid this situation. With this option, the users also have the opportunity to adjust when the system will shut down. This is specified with the next parameter (field: condensation differential parameter). This parameter is optional and EnergyPlus will use the SimpleOff strategy when this parameter is not specified.

#### Field: Condensation Control Dewpoint Offset

This optional parameter is only valid with the SimpleOff condensation handling algorithm (see previous input parameter). It establishes the difference between the calculated dew-point temperature of the space and the allowed surface temperature to which the surface can drop before the radiant system shuts down in degrees Celsius. This parameter can be any positive, negative, or zero value. When this parameter is zero, the radiant system will shut down when the surface temperature drops to the dew-point temperature or below. When this parameter is positive, the radiant system will shut down when the surface is the number of degrees Celsius above the dew-point temperature. This allows some extra safety to avoid condensation. When this parameter is negative, the radiant system will shut down when the surface temperature is the number of degrees Celsius below the dew-point temperature. While not recommended, this strategy allows the user to simulate a situation where small amounts of condensation are tolerable.

#### Field: Number of Circuits

This optional input allows the user to choose between modeling each surface in the radiant system as a single hydronic circuit or to allow the program to divide the surface into multiple parallel hydronic circuits based on the next input field *Circuit Length*. To model as a single circuit choose *OnePerSurface*. To model as multiple circuits choose *CalculateFromCircuitLength*. It is recommended that *CalculateFromCircuitLength* be chosen. The default is *OnePerSurface* for backward compatibility with older versions of EnergyPlus.

#### Field: Circuit Length

The length in meters of each parallel hydronic circuit in a surface. Used when the previous input field is set to *CalculateFromCircuitLength*. The default is 106.7 meters (350 feet), which is the maximum circuit length allowed in Title 24.

An example IDF with a constant flow low temperature radiant system is shown below.

ZoneHVAC:LowTemperatureRadiant:ConstantFlow,

Resistive Zone Radiant Floor, !- name of CONSTANT FLOW low temperature radiant system

RadiantSysAvailSched, !- availability schedule

Resistive Zone, !- Zone name

Zn001:Flr001, !- Surface name or group

0.012, !- Hydronic tubing inside diameter {m}

400.0, !- Hydronic tubing length {m}

MeanAirTemperature, !- temperature control type

0.0004, !- maximum water volumetric flow rate {m3/s}

, !-schedule for flow rate (optional, non-existent means constant)

30000, !-Rated Pump Head in Pa

50, !-Rated Power Consumption in W

0.87, !-Motor Efficiency

0.1, !-Fraction of Motor Inefficiencies to Fluid Stream

Resistive Zone Radiant Water Inlet Node, !- heating water inlet node

Resistive Zone Radiant Water Outlet Node, !- heating water outlet node

RadHeatHighWaterTemp, !-high water temperature schedule

RadHeatLowWaterTemp, !-low water temperature schedule

RadHeatHighControlTemp, !-high control temperature schedule

RadHeatLowControlTemp, !-low control temperature schedule

Zone 1 Cooling Water Inlet Node, !- cooling water inlet node

Zone 1 Cooling Water Outlet Node, !- cooling water outlet node

RadCoolHighWaterTemp, !-cooling high water temperature schedule

RadCoolLowWaterTemp, !-cooling low water temperature schedule

RadCoolHighControlTemp, !- cooling high control temperature schedule

RadCoolLowControlTemp, !- cooling low control temperature schedule

SimpleOff, !- condensation control type

0.5, !- condensation control dewpoint offset  
 CalculateFromCircuitLength, !- Number of Circuits

106.7; !- Circuit Length

### Low Temperature Radiant Constant Flow (ZoneHVAC) Outputs

HVAC,Average,Zone Radiant HVAC Heating Rate [W]

HVAC,Sum,Zone Radiant HVAC Heating Energy [J]

HVAC,Average,Zone Radiant HVAC Cooling Rate [W]

HVAC,Sum,Zone Radiant HVAC Cooling Energy [J]

HVAC,Average,Zone Radiant HVAC Mass Flow Rate [kg/s]

HVAC,Average,Zone Radiant HVAC Injection Mass Flow Rate [kg/s]

HVAC,Average,Zone Radiant HVAC Recirculation Mass Flow Rate [kg/s]

HVAC,Average,Zone Radiant HVAC Inlet Temperature [C]

HVAC,Average,Zone Radiant HVAC Outlet Temperature [C]

HVAC,Average,Zone Radiant HVAC Pump Inlet Temperature [C]

HVAC,Average,Zone Radiant HVAC Pump Electric Power[W]

HVAC,Sum,Zone Radiant HVAC Pump Electric Energy [J]

HVAC,Average,Zone Radiant HVAC Pump Mass Flow Rate [kg/s]

HVAC,Average,Zone Radiant HVAC Pump Fluid Heat Gain Rate [W]

HVAC,Sum,Zone Radiant HVAC Pump Fluid Heat Gain Energy [J]

HVAC,Sum,Zone Radiant HVAC Moisture Condensation Time [s]

HVAC,Sum,Zone Radiant HVAC Cooling Fluid Heat Transfer Energy [J]

HVAC,Sum,Zone Radiant HVAC Heating Fluid Heat Transfer Energy [J]

#### Zone Radiant HVAC Heating Rate [W]

This field reports the heating input rate to the low temperature radiant system in Watts. This is the heat source to the surface that is defined as the radiant system. The heating rate is determined by the zone conditions and the control scheme defined in the user input.

#### Zone Radiant HVAC Heating Energy [J]

This field reports the heating input to the low temperature radiant system in Joules. This is the heat source to the surface that is defined as the radiant system. The heating rate is determined by the zone conditions, the control scheme defined in the user input, and the timestep.

#### Zone Radiant HVAC Cooling Rate [W]

This field reports the cooling input rate to the low temperature radiant system in Watts. This is the heat sink to the surface that is defined as the radiant system. The cooling rate is determined by the zone conditions and the control scheme defined in the user input.

#### Zone Radiant HVAC Cooling Energy [J]

This field reports the cooling input to the low temperature radiant system in Joules. This is the heat sink to the surface that is defined as the radiant system. The cooling rate is determined by the zone conditions, the control scheme defined in the user input, and the timestep.

#### Zone Radiant HVAC Mass Flow Rate [kg/s]

This field reports the mass flow rate of water through the low temperature radiant system in kilograms per second. This should be identical to the pump flow rate for the system.

#### Zone Radiant HVAC Injection Mass Flow Rate [kg/s]

This field reports the mass flow rate of water that is injected into the radiant system from the main loop. A valve will control the injection and recirculation mass flow rates (see next field) to match the temperature controls specified by the user and dictated by the current simulation conditions.

#### Zone Radiant HVAC Recirculation Mass Flow Rate [kg/s]

This field reports the mass flow rate of water that is recirculated from the radiant system outlet and mixed with the injection flow from the main loop. A valve will control the injection and recirculation mass flow rates (see next field) to match the temperature controls specified by the user and dictated by the current simulation conditions.

#### Zone Radiant HVAC Inlet Temperature [C]

This field reports the temperature of water entering the low temperature radiant system in Celsius. This may differ from the inlet node temperature for the component since this component has its own local secondary loop.

#### Zone Radiant HVAC Outlet Temperature [C]

This field reports the temperature of water leaving the low temperature radiant system in Celsius. This may differ from the outlet node temperature for the component since this component has its own local secondary loop.

#### Zone Radiant HVAC Pump Inlet Temperature [C]

This field reports the temperature of water entering the low temperature radiant system pump in Celsius. This may differ from the inlet node temperature for the component since this component has its own local secondary loop. It is assumed that the pump is upstream of the radiant system.

#### Zone Radiant HVAC Pump Electric Power [W]

This field reports the rate of electric power consumption for the pump which supplies flow to the constant flow radiant system in Watts.

#### Zone Radiant HVAC Pump Electric Energy [J]

This field reports the electric power consumption for the pump which supplies flow to the constant flow radiant system in Joules.

#### Zone Radiant HVAC Pump Mass Flow Rate [kg/s]

This field reports the mass flow rate of water through the low temperature radiant system pump in kilograms per second. This should be identical to the flow rate for the system.

#### Zone Radiant HVAC Pump Fluid Heat Gain Rate [W]

This field reports the rate at which heat is added to the fluid stream as it passes through the pump in Watts. This heat is reflected in the radiant system inlet temperature which will be different from the pump inlet temperature if this field has a non-zero value.

#### Zone Radiant HVAC Pump Fluid Heat Gain Energy [J]

This field reports the amount of heat energy added to the fluid stream as it passes through the pump in Joules. This heat is reflected in the radiant system inlet temperature which will be different from the pump inlet temperature if this field has a non-zero value.

#### Zone Radiant HVAC Moisture Condensation Time [s]

This field reports the amount of time when condensation is occurring. When using the Off condensation control, this simply reports the amount of time when condensation occurs. When using the SimpleOff condensation control, this indicates the amount of time when the system has been shut off because of the potential danger of condensation.

#### Zone Radiant HVAC Cooling Fluid Heat Transfer Energy [J]

The heat transfer energy for the cooling fluid connection, in Joules.

#### Zone Radiant HVAC Heating Fluid Heat Transfer Energy [J]

The heat transfer energy for the heating fluid connection, in Joules.

### ZoneHVAC:LowTemperatureRadiant:Electric

This low temperature radiant system (electric) is a component of zone equipment that is intended to model any “radiant system” where electric resistance heating is used to supply energy (heat) to a building surface (wall, ceiling, or floor). The component is controlled by the radiant system controls that are defined in the syntax below and this control does not require the use of a zone thermostat unless the unit is being autosized. Note also that because this unit does not require a thermostat that in cases where no other systems are serving the zone in which this system resides that it will use the heating equipment priority to determine which system will run first. If the radiant system is serving a zone with forced air equipment, the radiant system will follow the priority order established by the zone thermostat but will still base its response on the controls defined by the user for the radiant system.

The control is accomplished by varying the electrical power supplied to the unit. This model covers either a radiant panel system or wires embedded in entire walls, floors, or ceilings. It is not intended to simulate high temperature electric or gas radiant heaters. Those devices will be handled by a separate model and different input syntax. Low temperature radiant systems that use water flowing through tubes to provide heat to the system should also be defined using separate input syntax (ref: Low Temp Radiant System:Hydronic).

#### Field: Name

This field is an unique user assigned name for an instance of an electric low temperature radiant system. Any reference to this unit by another object will use this name.

#### Field: Availability Schedule Name

This field is the name of the schedule (ref: Schedule) that denotes whether the electric low temperature radiant system can operate during a given time period. A schedule value less than or equal to 0 (usually 0 is used) denotes that the unit must be off for that time period. A value greater than 0 (usually 1 is used) denotes that the unit is available to operate during that time period. If this field is left blank, the schedule has a value of 1 for all time periods.

#### Field: Zone Name

This field is the name of the zone (Ref: Zone) in which the electric low temperature radiant system is principally located and intended to affect. A system that is between two zones will still act upon each zone; however, the zone name referenced here should be the zone that controls the radiant system response.

#### Field: Surface Name or Radiant Surface Group Name

This field is the name of the surface (Ref: BuildingSurface) or surface list (Ref: ZoneHVAC:LowTemperatureRadiant:SurfaceGroup) in which the hydronic tubing is embedded/contained. This specification attaches the source or sink from the radiant system to a particular surface and the contribution of the system to the heat balances of that surface. If this field is a surface list, then the source or sink is attached to all of the surfaces in the list with the radiant system surface group defining the breakdown of how flow rate is split between the various surfaces. Base surfaces (e.g., BuildingSurface:Detailed), door surfaces and internal mass are valid. Window surfaces are not valid surface types for embedded radiant systems.

#### Field: Heating Design Capacity Method

Enter the method used to determine the maximum electrical power (heating design capacity ) or enter the method for scalable sizing the maximum electrical power of low temperature radiant electric unit. Input allowed is either *HeatingDesignCapacity*, *CapacityPerFloorArea*, and *FractionOfAutosizedHeatingCapacity*. If this input field is left blank or zero, then autosizing is assumed. *HeatingDesignCapacity* means user specifies the magnitude of maximum or nominal heating capacity or the program calculates the maximum or nominal design heating capacity if autosize is specified. *CapacityPerFloorArea* means the program calculates the design heating capacity from user specified heating capacity per floor area and floor area of the zone served by the low temperature radiant electric unit. *FractionOfAutosizedHeatingCapacity* means the program calculates the design heating capacity from user specified fraction and the auto-sized design heating capacity. The default method is *HeatingDesignCapacity*.

#### Field: Heating Design Capacity {W}

This field is for the maximum amount of electric energy rate (electric power) converted into heat in low temperature radiant electric unit in watts. This input field is autosizable. The controls for the radiant system will vary the amount of power supplied to the surface between zero input and the maximum power specified in this field as the lower and upper bounds, respectively. Note that if the user elects to autosize this field that a standard zone thermostat such as would be used for a forced air system must be defined as autosizing calculations are based on the zone thermostat value and not on the low temperature radiant electric unit control values. The default input for this input field is autosize.

#### Field: Heating Design Capacity Per Floor Area {W/m2}

Enter the heating capacity per unit floor area in m3/s-m2 of low temperature radiant electric system. This field is required field when the Heating Design Capacity Method is *CapacityPerFloorArea*. The program calculates the heating capacity from floor area of the zone served by the low temperature radiant electric unit and the heating capacity per unit floor area value specified by the user. This field may be left blank.

#### Field: Fraction of Autosized Heating Design Capacity {-}

Enter the heating capacity as a fraction of the autosized heating capacity of low temperature radiant electric unit. This input field is required when the Heating Design Capacity Method is *FractionOfAutosizedHeatingCapacity*. The program calculates the heating capacity from the design autosized heating capacity and user specified fraction. Design day sizing must be specified. This field may be left blank. The default value is 1.0.

#### Field: Temperature Control Type

This field specifies along with the throttling range and setpoint schedules how the user wishes to control the low temperature electric radiant system. The temperature denoted in the setpoint schedule can refer to one of three different temperatures: the zone mean air temperature, the zone mean radiant temperature, the zone operative temperature, the outdoor dry-bulb temperature, or the outdoor wet-bulb temperature. The choice of temperature is controlled by the current field—temperature control type. The user must select from the following options:

MeanAirTemperature

MeanRadiantTemperature

OperativeTemperature

OutdoorDryBulbTemperature

OutdoorWetBulbTemperature

Operative temperature for radiant system controls is the average of Mean Air Temperature and Mean Radiant Temperature. If the user does not select a control type, **MeanAirTemperature** control is assumed by EnergyPlus. See the throttling range and control temperature schedule fields below for more information.

#### Field: Heating Throttling Range

This field specifies the range of temperature in degrees Celsuis over which the radiant system throttles from zero heat input via the electric resistance wires up to the maximum defined by the maximum electrical power field described above. The throttling range parameter is used in conjunction with the control temperature (see below) to define the response of the system to various zone conditions. The heating control temperature schedule specifies the “setpoint” temperature where the power input to the system is at half of the maximum power input. For example, if the heating control temperature setpoint is currently 15°C and the heating throttling range is 2°C, the electrical power supplied to the radiant system will be zero when the controlling temperature (MAT, MRT, Operative Temperature, ODB, or OWB; see control type field above) is at or above 16°C and the maximum power input when the controlling temperature is at or below 14°C. This represents a throttling range of 2°C around the setpoint of 15°C. In between 14°C and 16°C, the power input to the radiant system is varied linearly.

#### Field: Heating Setpoint Temperature Schedule Name

This field specifies the heating setpoint or control temperature for the radiant system in degrees Celsius. Used in conjunction with the previous field (heating throttling range), it will define whether or not the system is running and the current power input to the radiant surface. Power input to the system is varied linearly around the setpoint temperature based on the throttling range and the maximum electrical power parameters (see above). It should be noted that this control schedule will allow different setpoint temperatures throughout the year for heating. In addition, this schedule may be different that the thermostatic control schedule defined for overall operation of components serving the zone in which the radiant system is located. The thermostatic control determines whether or not there is a heating or cooling load in the space and thus whether the systems should be operating. This field simply controls the flow rate to the radiant system.

An example IDF with an electric low temperature radiant system is shown below.

ZoneHVAC:LowTemperatureRadiant:Electric, Zone 2 Radiant Floor,

RadiantPanelAvailSched , ! Availability schedule

EAST ZONE , ! Zone name (name of zone system is serving)

Zn002:Flr001 , ! Surface name (name of surface system is embedded in)

HeatingDesignCapacity, !- Heating Design Capacity Method

10000, !- Heating Design Capacity{ W }

, !- Heating Design Capacity Per Floor Area{ W / m2 }

, !- Fraction of Autosized Heating Design Capacity{ -}

MeanAirTemperature, ! control type (control on mean air temperature)

2.0 , ! heating throttling range (in C)

Radiant Heating Setpoints ; ! heating setpoint temperatures

### Low Temperature Radiant Electric (ZoneHVAC) Outputs

HVAC,Average, Zone Radiant HVAC Electric Power[W]

HVAC,Sum, Zone Radiant HVAC Electric Energy [J]

HVAC,Sum,Zone Radiant HVAC Heating Energy [J]

HVAC,Average, Zone Radiant HVAC Heating Rate [W]

#### Zone Radiant HVAC Electric Power [W]

This field reports the rate at which electric energy is “burned” in the low temperature radiant system in Watts. This is the heat source to the surface that is defined as the radiant system. The heating rate is determined by the zone conditions and the control scheme defined in the user input.

#### Zone Radiant HVAC Electric Energy [J]

This field reports the amount of electric energy “burned” in the low temperature radiant system in Joules. This is the heat source to the surface that is defined as the radiant system. The heating rate is determined by the zone conditions, the control scheme defined in the user input, and the timestep.

#### Zone Radiant HVAC Heating Energy [J]

#### Zone Radiant HVAC Heating Rate [W]

These outputs are the heating provided by the low temperature radiant system to the zone, in Watts or Joules.

### ZoneHVAC:LowTemperatureRadiant:SurfaceGroup

A low temperature radiant system (hydronic or electric) may consist of multiple active surfaces that are serving to condition the space. Surfaces that act serially can be specified as multiple radiant systems using the standard radiant system input described above. However, if the multiple surfaces act in parallet, the Radiant System Surface Group input line is used to specify which surfaces are acting in a coordinated fashion and how flow rate is split between the surfaces. This list of surfaces (the name it is assigned) replaces the name of a single surface in the radiant system input described above. Note that all of the surfaces within a single list must be a part of the same zone and that the zone of these surfaces must also match the zone the radiant system is attempting to condition.

#### Field: Name

This field is an unique user assigned name for the list of surfaces that are acting in coordination with one another. Any reference to this list by a radiant system will use this name.

#### Field Set: Surface Name, Flow Fraction to Surface

The pairs of Surface Name, Flow Fraction to Surface are used in several objects. There can be up to 10 specified. The object is extensible so more can be added.

#### Field: Surface <x> Name

This field is the name of a surface in the zone being conditioned by the radiant system. Base surfaces (e.g., BuildingSurface:Detailed), door surfaces and internal mass are valid. Window surfaces are not valid surface types for embedded radiant systems.

#### Field: Flow Fraction for Surface <x>

This field is the fraction of the total radiant system flow rate that is being sent to this particular surface. Note that the Surface Name/Surface Flow Fraction pair can be repeated up to 10 times. Flow rate fractions must sum to unity, otherwise the program will not accept the input as valid.

An example IDF with an electric low temperature radiant system is shown below.

ZoneHVAC:LowTemperatureRadiant:SurfaceGroup,

Zone 1 Radiant Surfaces, !- name of surface list

Zn001:Flr001, !- Surface name 1

0.75, !- Flow fraction for surface 1

Zn001:Roof001, !- Surface name 2

0.25; !- Flow fraction for surface 2