Volume

6

DOE-2.3

Building Energy Use and Cost Analysis Program
Volume 6: New Features
February 2016 (Release Candidate Version)

DOE-2.2 FEATURES NOT YET INCLUDED IN DOE-2.3
ENHANCEMENTS TO GROUND-LOOP HEAT EXCHANGERS
DATA CENTER SIMULATION ENHANCEMENTS
DESIGN SIZING ENHANCEMENTS
WATERSIDE EQUIPMENT IN SERIES
COOLING TOWER WETBULB RESET CONTROL
ECONOMIZER DEWPOINT CONTROL
ZONAL EXTRACTION TEMPERATURE DIFFERENTIALS
SPACE EQUIPMENT LOADS TO RETURN AIR
RESIDENTIAL VARIABLE REFRIGERANT FLOW SYSTEM
PIU TERMINAL ENHANCEMENTS
CHW-LOOP ECONOMIZER COOLING
UNDERFLOOR HVAC AIR DISTRIBUTION

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Volume 6: New Features

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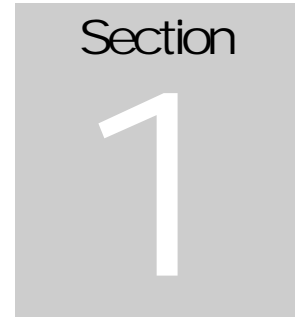Phone 805.553.9000 • Fax 805.532.3401

Acknowledgements

DOE-2.3, both the program and its documentation, are based upon earlier versions of DOE-2. The DOE-2 family of programs was created primarily through a partnership between James J. Hirsch & Associates (JJH) and Lawrence Berkeley National Laboratory (LBNL) with additional contributions, over a twenty five year period, from a large number of individuals and institutions around the world. Support for the continued development of DOE-2, over its two decades of wide distribution, has come from many public and private agencies, companies and educational institutions around the world. The primary support for DOE-2 development, however, has come from public funds provided by the United States Department of Energy (USDOE) and the United States electric and gas utility industry; particularly the USDOE Office of Energy Efficiency and Renewable Energy Building Technologies Program, Southern California Edison Company's Energy Efficiency Division, and the Electric Power Research Institute's Customer Systems Division.

Authorship of the DOE-2.3 program components and documentation is an ongoing team effort that has its roots in previous versions going back over twenty-five years and we expect will continue into future decades. The contributions to DOE-2, both directly as authors and indirectly in the form of advice, comment and testing or feedback, are too numerous to catalog here; however, the primary authors are mentioned below in alphabetical order. Currently, and over the past decade, Marlin Addison, Scott Criswell, Steve Gates, Jeff Hirsch, and Kevin Madison, as consulting staff for JJH, are the major contributors to DOE-2.3. Fred Buhl, Ender Erdem, Kathy Ellington and Fred Winkelmann, as staff members of the Environmental Energy Technologies Division's Simulation Research Group at LBNL, were major contributors to the initial version of DOE-2.3. The primary contributors to the previous versions of DOE-2 (2.1E, 2.1D, 2.1C, etc) were Fred Buhl, Ender Erdem, Kathy Ellington, Steve Gates, Jeff Hirsch and Fred Winkelmann, as LBNL staff and Steve Gates and Jeff Hirsch as consulting staff for JJH.

The authors of DOE-2.3 also wish to acknowledge many persons who, apart from the financial support provided by their organizations, have provided vision and insight that has been instrumental to the ongoing support of the DOE-2 family of products, including DOE-2.1, DOE-2.3, PowerDOE and eQUEST. In particular we express our thanks to Gregg Ander and Janith Johnson formerly of Southern California Edison Company.

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Introduction to New Features

This version of DOE-2 incorporates several new or revised features:

- DOE-2.2 features not currently included in this DOE-2.3

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- Design sizing enhancements

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DOE-2.2 FEATURES NOT CURRENTLY INCLUDED IN DOE-2.3

Introduction

DOE-2.3 required a significant restructuring in order to accommodate the enhanced design-sizing calculations (see the section "Design-Sizing Enhancements"), and its new iterative structure. At this time, DOE-2.3 is release candidate not intended to fully replace DOE-2.2.

Not all features that exist in DOE-2.2 have been ported over into 2.3. The following is a summary of the 2.2 features not currently ported over into 2.3.

TROMBE-WALL-NV

Trombe walls are not currently implemented in DOE-2.3. This command is not functional , but has not been disabled.

TROMBE-WALL-V

Trombe walls are not currently implemented in DOE-2.3. This command is not functional, but has not been disabled.

SPACE

Virtually all of the SPACE command keywords are functional, except for a few which are integrated with the HVAC system:

TROMBE-WALL-NV

Trombe walls are not currently implemented in DOE-2.3.

TROMBE-WALL-V

Trombe walls are not currently implemented in DOE-2.3.

SUNSPACE

Sunspaces are not currently implemented in DOE-2.3

SYSTEM

TYPE

The following system TYPEs are not currently implemented:

PTAC	Not currently implemented, but slated for implementation
HVSYS	Not currently implemented, but slated for implementation
EVAP-COOL	Not currently implemented, but slated for implementation
RESVVT	Not currently implemented. This system is actually better known as Carrier's PVVT system (The DOE-2 PVVT system is something else entirely). If implemented, it will be configured as a commercial application, rather than residential which is of limited value.

RESYS	Not currently implemented; superceded by RESYS2 system.
SZCI	Not currently implemented, and may be dropped. This system type has not been popular for over 40 years.
FPH	Not currently implemented. Can be approximated using a baseboard heater.
PTGSD	Not currently implemented. Major problems have been discovered in the DOE-2.2 algorithm pertaining to the moisture balance calculations and the energy consumption at part load. Future status has not been resolved.
SUM	Not currently implemented
FNSYS1	Not currently implemented, and may not be for the forseeable future. User functions are not currently implemented in DOE-2.2

HEAT-SOURCE

The following types have not been implemented:

DHW-LOOP	Not currently implemented.
GAS-HYDRONIC	Not currently implemented. Relies upon the gas heat-pump algorithm
GAS-HEAT-PUMP	Not currently implemented. A recent search suggests that this technology is no longer available in the commercial market.

ZONE-HEAT-SOURCE

The following types have not been implemented:

HEAT-PUMP	In the context of a zone reheat coil, this configuration is not know to exist.
DHW-LOOP	Not currently implemented.
GAS-HYDRONIC	Not currently implemented. Relies upon the gas heat-pump algorithm
GAS-HEAT-PUMP	Not currently implemented. A recent search suggests that this techmology is no longer available in the commercial market.

PREHEAT-SOURCE

The following types have not been implemented:

DHW-LOOP	Not currently implemented.
GAS-HYDRONIC	Not currently implemented. Relies upon the gas heat-pump algorithm

BASEBOARD-SOURCE

The following types have not been implemented:

DHW-LOOP	Not currently implemented.

GAS-HYDRONIC   Not currently implemented. Relies upon the gas heat-pump algorithm

HP-SUPP-SOURCE

The following types have not been implemented (only electric, furnace and hot-water are implemented):

HEAT-PUMP

DHW-LOOP   Not currently implemented.

GAS-HYDRONIC   Not currently implemented. Relies upon the gas heat-pump algorithm

GAS-HEAT-PUMP   Not currently implemented. A recent search suggests that this techmology is no longer available in the commercial market.

STEAM   Heat pumps are unlikely in applications where steam exists.

CONDENSER-TYPE

Air-cooled and water-cooled condensers are implemented. The following types have also been implemented, but not tested:

EVAP-PRECOOLED   Implemented, but not tested

EVAP-COOLED   Implemented, but not tested

HUMIDIFIER-TYPE

Only electric humidifiers have been implemented. The following types have not been implemented:

HOT-WATER   Not currently implemented.

DHW-LOOP   Deleted

GAS-HYDRONIC   Deleted

HEAT-PUMP   Deleted

FURNACE   Not currently implemented; technology not known to exist.

GAS-HEAT-PUMP   Deleted

FAN-CONTROL

The 2-speed fan control code-word is not implemented, but two-speed fan operation can be simulated in the PVVT system using AIR/TEMP-CONTROL = TWO-SPEED.

COMPRESSOR-TYPE

This keyword is currently not implemented in DOE-2.3. However, two-speed or variable-speed compressors can be simulated via the specification of an appropriate part-load curve-fit.

WASTE-HEAT-USE

This feature is not currently implemented (SPACE-HEAT, DHW-HEAT, SPACE+DHW-HEAT)

OA-FROM-SYSTEM

This feature is not currently implemented. The plan is to supplement this feature with dedicated outside air systems.

DESICCANT SYSTEMS

The desiccant systems in DOE-2.2 were discovered to have significant issues with the moisture balance calculations, and energy consumption at part load. Implementation of this feature in DOE-2.3 will be delayed indefinitely until these issues can be resolved.

WATERSIDE ECONOMIZERS

Waterside economizers can consist of either:

- Packaged DX air handler – This configuration consists of an additional coil in each packaged air handler. This coil is located upstream of the evaporator and precools the airflow. This coil is supplied with water from a cooling tower.

  This configuration exists in DOE-2.2, but is not currently implemented in DOE-2.3.

- Precooling of CHW loop – This configuration consists of a heat exchanger in the central plant that cools a chilled-water loop using water from a cooling tower. No additional cooling coils are required in the air handlers.

  This configuration exists in DOE-2.2, but operation is limited to hours when it can satisfy the entire cooling load; it cannot pick up a partial load with the chillers satisfying the remainder of the load. This feature is implemented in DOE-2.3, and is enhanced to allow the economizer to precool the return water, with chillers operating to meet the remainder of the load.

ENERGY-RECOVERY VENTILATORS

This capability is not currently implemented in DOE-2.3

NIGHT-VENTILATION

Night ventilation, where the air handler fans operate at night in a reduced flow mode to cool spaces, is not currently implemented in DOE-2.3. Note that natural ventilation, where occupants open windows to cool spaces, is implemented.

REFRIGERATED DISPLAY FIXTURES

This feature was rendered obsolete in DOE-2.2 with the development of DOE-2.2R, the refrigeration version. For this reason, this capability will not be included in DOE-2.3

ZONE

SIZING-OPTION

The enhanced sizing calculations have made this keyword obsolete.

ZONE-FAN-T-SCH

This keyword used to control the fan in fan-powered VAV boxes. It has been replaced by ZONE-FAN-RUN = (HEATING-ONLY, HEATING/DEADBAND, CONTINUOUS), HEATING/COOLING).

INDUCED-AIR-ZONE

For fan-powered VAV boxes, this keyword has been replaced with INDUCED-AIR-SOURCE = (ZONE-RECIRC, RETURN-PLENUM, RETURN-AIR).

TROMBE WALLS

Trombe walls are not currently implemented in DOE-2.3

SUNSPACE

All sunspace keywords are not currently implemented in DOE-2.3

ICE SKATING RINKS

This feature is not currently implemented in DOE-2.3

REFRIGERATED DISPLAY FIXTURES

This feature was rendered obsolete in DOE-2.2 with the development of DOE-2.2R, the refrigeration version. For this reason, this capability will not be included in DOE-2.3

FAN-ASSISTED NATURAL VENTILATION

Introduction

Previously, natural ventilation options included a constant-volume air-change method, and a wind/temperature-driven model. The constant-volume air-change method has been modified to include a linear adjustment for wind speed. New options have been added to allow for fan-assisted ventilation. Fan-assisted ventilation may operate on its own, or supplement either of the two existing methods.

In general, natural ventilation applies only to select single-zone systems (TYPE = RESYS, RESYS2, PSZ, PVVT SZRH, EVAP-COOL) and single-duct systems (TYPE = PVAVS, VAVS, RHFS). Fan-assisted ventilation applies only to the single-zone subset of systems; not single-duct.

Building Description Language Changes

The following keywords were implemented or modified to facilitate the analysis of fan-assisted ventilation.

SYSTEM

VENT-METHOD

Takes a code-word that specifies how the natural ventilation rate is to be calculated. Allowed values are:

NONE	No natural ventilation is allowed.
AIR-CHANGE	The ventilation rate is specified in air changes per hour, relative to a wind speed of 10 miles/hour, via the keyword NATURAL-VENT-AC. The air change rate is adjusted hourly as a function of windspeed, but is not adjusted for inside-outside temperature difference.
S-G	Specifies the "Sherman-Grimsrud" method in which the air change rate depends on wind speed, inside-outside temperature difference, and wind shielding of the building. In this case, the keywords MAX-VENT-RATE, HOR-VENT-FRAC, and FRAC-VENT-AREA are applicable.
FAN-ONLY	Natural ventilation is always assisted by a fan. The air change rate is specified using FAN-VENT-AC. Note: fan-assisted natural ventilation is allowed for single-zone systems only.
AIR-CHANGE+FAN	The program will first attempt to meet the space load without fan assist as described for AIR-CHANGE, above. If the load cannot be met, the program will use the exhaust fan assisted method as described for FAN-ONLY. Note: fan-assisted natural ventilation is allowed for single-zone systems only.
SG+FAN	The program will first attempt to meet the space load without fan assist as described for S-G above If the load cannot be met, the program will use the fan-assisted method as described for FAN-ONLY. Note: fan-assisted natural ventilation is allowed for single-zone systems only.

VENT-MAX-T

This is an alternate space temperature setpoint for the control zone of the system served by natural ventilation. This allows an override of the normal cooling thermostat during natural ventilation, with the assumption that occupants will be comfortable at a higher space temperature due to high natural ventilation air change rates.

NATURAL-VENT-AC

For VENT-METHOD = AIR-CHANGE, the peak number of air changes per hour due to natural ventilation through open windows, when the local wind speed is 10 miles/hour. This value is adjusted linearly for wind speed, but not for indoor to outdoor temperature difference.

FAN-VENT-AC

For fan-assisted natural ventilation methods, the peak number of air changes per hour during fan-assissted natural ventilation.

NATURAL-VENT-KW

The kW of the natural ventilation assisting fan (otherwise known as a whole house fan). This value is entered when a whole house fan is used to perform the natural cooling; the value entered is the kW used by the fan during a full hour of operation. The hour value is calculated as this value times the runtime of the fan during the hour; the run time is calculated assuming the fan is operated to maintain the VENT-TEMP-SCH with a flow of FAN-VENT-AC.

VENT-EXH-ZONE

Accepts the U-name of an unconditioned zone thru which natural ventilation from conditioned zones is exhausted. This keyword is used only with the fan-assisted VENT-METHOD options to simulate a whole-house fan exhausting into an attic. Ventilation from each conditioned zone served by the SYSTEM will exhaust to this zone when the natural ventilation fan is running. The temperature of the exhaust entering this zone will be the weighted average of each conditioned zone's temperature.

ENHANCEMENTS TO GROUND-LOOP HEAT EXCHANGERS

Introduction

Ground-loop heat exchangers have existed in the program for many years, but only in a stand-alone configuration. The well field had to be sized large enough to handle the maximum heating and cooling loads encountered, both peak and annual, without assistance from a supplemental boiler or heat-rejection device. If undersized, then the loop temperature could exceed either the maximum or minimum alarm temperature, and the simulation would issue an error and stop. As well-drilling can be quite expensive, systems sized to meet the entire load could prove to be not cost effective.

Multi-year simulations were also a problem. The performance of a ground loop can vary substantially from the first year to the tenth year, especially in the typical situation where the annual cooling loads are substantially greater than the annual heating loads. In this case, the ground may become saturated with heat as the years progress, with a subsequent rise in summer cooling temperatures as the years progress. The program recognized this and roughly approximated a multi-year history using the peak heating and cooling loads and time of occurrence to generate a sinusoidal loading function to pre-charge the ground for the actual year of simulation.

The program now contains the following enhancements:

- Hybrid ground-loop systems – The program now allows supplemental heating and cooling to be provided via a boiler and/or a heat-rejection device such as a fluid cooler. This allows the size of the well field to be reduced, substantially in many cases. For example, a well field can be sized just large enough to provide for the annual heating loads, with all excess cooling rejected via a fluid cooler. This will often be the most energy efficient and cost-effective strategy.

- Multi-year simulations – Rather than using an approximate loading history generated using a sinusoidal loading function between peak heating and cooling loads, the program now allows for either full multi-year simulations, or simulation of previous years using a weighted sample of the years.

- Reporting of annual temperature profiles – A new report, PS-O has been implemented to help in the assessment of ground-loop systems. The report is a scatter plot of circulation loop's supply temperature vs. the time of day. One report is generated for hours that a net heating load exists, and another for hours that a net cooling load exists.

- "Auto-sizing" of ground-loop heat exchangers - This feature allows the user to make a preliminary selection of the well configuration and other characteristics. Based on peak heating/cooling loads, the program will calculate the total number of boreholes required, and adjust the field multiplier to ensure the sizing is approximately correct. This is a starting point only; the user will still need to make successive runs to optimize the system.

- Coupling of water-to-water heat pumps and 3-loop chillers to ground-loop heat exchangers – Previously, chiller/heat-pumps and 3-loop chillers could be coupled only to lake/well systems, not ground-loop heat exchangers. This restriction has been removed, and the special lake/well loop type has been eliminated.

  Included as part of this work is a new heating coil algorithm that works with the reduced heating loop temperatures associated with water-to-water heat pumps.

This enhancement is funded by Department of Energy under the American Recovery and Reinvestment Act and in collaboration with ClimateMaster and Oak Ridge National Laboratory.

Integration with a Cooling Tower and/or Boiler

The program can simulate a GROUND-LOOP-HX together with a heat rejection device and/or boiler. Often, it may not be economical to size the well field large enough to handle the peak cooling loads, especially for buildings that are cooling-dominated. In this case, it may be desirable to install a fluid cooler in series with the well field. This is known as a hybrid system. In a similar fashion, a boiler may be added to a system that is heating-dominated.

When a cooling tower and/or boiler is attached to the same loop as a ground-loop heat exchanger, the program assumes that the supplemental equipment is in series with the well field, and downstream of the well field; this configuration cannot be changed. If the fluid temperature leaving the ground-loop heat exchanger is within the circulation loop's cooling/heating setpoints, then the loop temperature floats with the leaving ground-loop temperature. If the temperature exceeds the loops's cooling setpoint, or drops below the heating setpoint, then supplemental equipment will operate to maintain the loop temperature at setpoint.

As with other equipment in series, the CIRCULATION-LOOP:DOWNSTREAM-SPLIT specifies the fraction of the design heating or cooling load to be picked up by the downstream equipment, which in this case is always the hybrid boiler or heat-rejection component(s). If the ground-loop's SIZE-FIELD-MULT = YES, then the field multiplier is also sized based on this value (1.0 – DOWNSTREAM-SPLIT for the GLHX, as it is upstream).

Note that the DOWNSTREAM-SPLIT (and default cooling tower sizing) does not have to be very large for the supplemental heat-rejection component to pick up the majority of the annual cumulativecooling load. For example, a tower sized to a DOWNSTREAM-SPLIT of 0.3 may often pick up more than half of the annual cooling load.

The CIRCULATION-LOOP:SERIES-BYPASS is not active for hybrid systems; the supplementary equipment is always assumed to be bypassed when inactive. However, a keyword is provided to specify whether the ground-loop heat exchanger should be bypassed when it is counterproductive, CIRCULATION-LOOP:GLHX-BYPASS. For example, if the circulation loop is resetting the cooling setpoint using wetbulb reset, then there may be times when the cooling setpoint is so low that the tower may pull heat out of the ground-loop heat exchanger, if the ground-loop is not bypassed. This may or may not be desirable.

Example of a Hybrid Ground-Loop Heat Exchanger System

This example defines a ground-loop heat-exchanger system with a supplementary fluid cooler. The fluid cooler is sized to pick up 30% of the peak load, and utilizes wetbulb-reset control. The GLHX is not autosized , and is not bypassed when counterproductive.

```
"GSHP Loop Pump" = PUMP
   NUMBER            = 1
   MOTOR-CLASS       = HI-EFF
   CAP-CTRL          = VAR-SPEED-PUMP
   ..

"GSHP Water Loop" = CIRCULATION-LOOP
   TYPE              = WLHP
   LOOP-PUMP         = "GSHP Loop Pump"
   PIPE-HEAD         = 21.6
   LOOP-OPERATION    = SUBHOUR-DEMAND

   LOOP-DESIGN-DT    = 10
   DESIGN-HEAT-T     = 30
   DESIGN-COOL-T     = 85
   MAX-ALARM-T       = 110
   MIN-ALARM-T       = 10
```

```
    COOL-SETPT-CTRL    = WETBULB-RESET
    CW-AMBIENT-DT      = 7.0
    WETBULB-RATIO      = 0.0
    MIN-RESET-T        = 55

    DOWNSTREAM-SPLIT   = 0.3
    GLHX-BYPASS        = NO
    ..

"GSHP Fluid Cooler" = HEAT-REJECTION
    TYPE               = FLUID-COOLER
    CW-LOOP            = "GSHP Water Loop"
    CAPACITY-CTRL      = VARIABLE-SPEED-FAN
    ..

"GLHX (VertWell-CM)" = GROUND-LOOP-HX
    TYPE               = VERT-WELL-NEW
    CIRCULATION-LOOP   = "GSHP Water Loop"
    HX-HEAD            = 30

    CONFIGURATION      = "Rectangle-3x5"
    SIZE-FIELD-MULT    = NO
    FIELD-MULTIPLIER   = 1
    DEPTH              = 250
    SPACING            = 20

    NUM-OF-YEARS       = 20
    HISTORY-SETUP      = SAMPLE-YEARS
    ..
```

Building Description Language Changes

The following keywords were implemented or modified to facilitate the analysis of ground-loop heat exchangers.

SYSTEM

WLHP-CATEGORY

For water-cooled DX systems, selects the default rated entering water temperature for cooling. For water-source heat pumps, also selects the default rated entering water temperature for heating.

Cooling and heating capacities and efficiencies are defined for a specific set of rating temperatures, but different rating temperatures apply to cooling only units vs. heat pumps. And for heat pumps, different rating temperatures apply depending on the application. Choices are:

COOLING-ONLY   the default for cooling-only DX systems (not a heat pump), specifies that the rated conditions are for a cooling-only application. The condenser loop is assumed to be a conventional system having only heat-rejection devices (cooling towers), and no heating capability.

WATER-LOOP   specifies that the rated conditions are for a water-loop heat pump application. The attached circulation loop is assumed to have a boiler(s) and chiller(s), but no ground-loop heat exchanger.

GROUND-WATER   specifies that the rated conditions are for a ground-water heat pump application (although the DX units may be cooling-only). The attached circulation loop is

assumed to draw from a lake or open well (water taken directly from the lake or well).

GROUND-LOOP   specifies that the rated conditions are for a ground-loop heat pump application. The attached circulation loop is assumed to be coupled to a closed ground-loop heat exchanger consisting of either a horizontal or vertical well field.

This system may be a hybrid system, in which case a supplemental heat-rejection device, such as a fluid cooler, is included. A hybrid system may also include a boiler in addition to, or in place of, the heat rejection device.

For cooling only DX units, this keyword is optional. For heat pumps, this keyword is mandatory. The defaults for the keywords RATED-ECT and HT-RATED-ECT are set depending on this selection. If the COOLING-EIR and/or HEATING-EIR are allowed to default, the default value will be adjusted to match the temperatures of the specified rating class.

Table 1 Rated Water Temperatures for Condenser Rating Classes

WLHP-CATEGORY	RATED-ECT	HT-RATED-ECT
COOLING-ONLY	85.	N/A
WATER-LOOP	86.	68.
GROUND-WATER	59.	50.
GROUND-LOOP	77.	32.

As can be seen in the table, the rated water temperatures vary substantially depending on the application. For this reason, proper specification of this keyword is critical if you define the capacity or efficiency (alternatively, you may specify the RATED-ECT and HT-RATED-ECT keywords).

CIRCULATION-LOOP
TYPE
The LAKE/WELL circulation-loop type has been eliminated (the LAKE/WELL type of ground-loop heat exchanger still exists). Previously, this type existed only to ensure that chiller/heat pumps could attach only to GROUND-LOOP-HXs of TYPE = LAKE/WELL. This restriction has now been removed, so it is no longer necessary to distinguish LAKE/WELL loops from WLHP loops.

EQUIP-CONFIG
For hybrid ground-loop heat exchangers with supplemental heating and/or cooling (boilers and/or heat-rejection components), the progam always assumes the equipment is in series, with the ground-loop heat exchanger upstream of the supplemental equipment. For this reason, the EQUIP-CONFIG keyword is not used.

Like other loops with equipment in series, inactive equipment may be bypassed using the SERIES-BYPASS keyword.

DOWNSTREAM-SPLIT

For hybrid ground-loop heat pump systems consisting of a ground-loop heat exchanger and a supplemental cooling tower and/or boiler, the supplemental equipment is always located downstream of the ground-loop heat exchanger. In this case, the DOWNSTREAM-SPLIT specifies the fraction of peak heating or cooling load that the supplemental equipment is sized to satisfy. If the GROUND-LOOP-HX:SIZE-FIELD-MULT = YES, then the FIELD-MULTIPLIER will be defaulted based on the remaining portion allocated to the upstream equipment.

SERIES-BYPASS

When EQUIP-CONFIG = SERIES, specifies whether UPSTREAM or DOWNSTREAM equipment can be bypassed when inactive. The most common example would be two chillers in series, but with only one chiller operating. If the inactive chiller can be bypassed, then the pump head will be reduced.

This keyword also applies to a waterside economizer in series with a chiller.

There is a special case for a hybrid ground-source heat pump system consisting of a ground-loop heat exchanger and either a cooling tower and/or boiler. In this case, the boiler/tower is always in series downstream of the ground-loop heat exchanger, and is always bypassed when inactive (otherwise the cooling tower could loose significant amounts of heat during winter operation, which is not simulated); therefore SERIES-BYPASS is unused. A separate keyword, GLHX-BYPASS applies to the ground-loop heat exchanger.

GLHX-BYPASS

For a hybrid ground-source heat pump system, specifies whether the ground-loop heat exchanger (GLHX) can be bypassed when it is counter-productive (heating when the loop requires cooling, or cooling when the loop requires heating; the mode depends on the relative temperature of the GLHX vs. the loop return temperature).

NO	the default, specifies that the ground-loop heat exchanger cannot be bypassed. Even when the ground-loop is non-productive, such as when it is heating when the loop requires cooling, it will remain in the circuit, and the pump will have to overcome the head of the equipment.
	This type of configuration might be useful if the loop's cooling setpoint is reset based on outdoor wetbulb temperature. During times when the wetbulb is low, the tower can drop its temperature supplied to the building, dropping the return temperature. The ground-loop heat exchanger may then discharge surplus heat, which is then immediately removed by the tower. This might allow the cooling-mode loop temperature to be lower on average than it would be otherwise.
YES	specifies that ground-loop heat exchanger is bypassed when it is counter-productive. Pump head will be reduced in this situation.

Note that the supplemental hybrid equipment (cooling tower and/or boiler) is always bypassed when inactive. Otherwise the cooling tower could loose significant amounts of heat during winter operation, which is not simulated.

GROUND-LOOP-HX

TYPE

Previously, two algorithms were supported for vertical well fields, the original algorithm VERT-WELL-FIELD and an enhanced algorithm VERT-WELL-NEW. The original algorithm is now considered obsolete and has been eliminated. Use only VERT-WELL-NEW.

LOOP-SERIES-LOCN
While this keyword exists, it is inactive and cannot be modified by the user. If a hybrid system is specified consisting of a ground-loop heat exchanger and supplemental heating and/or cooling (boiler and/or heat-rejection), then the equipment is always assumed to be in series, with the ground-loop heat exchanger upstream of the supplemental equipment.

HX-BYPASS-FLOW
Specifies the fraction of the total loop flow that will be conditioned by this glhx, but that is bypassed around the glhx rather than flowing through the glhx. For a given glhx design and ground thermal properties, this will result in a reduction of the heat transfer capacity of the glhx.

Bypass may be utilized if the heat exchanger field is sized significantly smaller than the circulation loop flow, and full loop flow would result in an excessive pressure drop. For a variable flow loop, at lower flows all of the fluid flows through the ground field. Once the loop flow exceeds the glhx's design flow, then the surplus flow is bypassed.

NUM-OF-YEARS
The number of years of operation previous to the simulation year. The load profile assumed for the prior years is that generated in the initialization runs, defined by HISTORY-SETUP. A value of zero means that this year's analysis is the first year after the system was installed, so that the ground is at the undisturbed temperature. A value of 20 would mean that the ground loop has experienced the charge/discharge load profiles developed in the initialization run(s) for the previous twenty years.

HISTORY-SETUP
When the number of prior years (NUM-OF-YEARS) is non-zero, accepts a code word specifying the pattern of years to be simulated in building up the history:

ALL-YEARS	Performance of the building and the GSHP system (conventional or hybrid) in all of the prior years are to be simulated. For example, if NUM-OF-YEARS = 29, then all 29 years prior to the actual year will be simulated to build up the history of the well field. For complex buildings, this option may result in long run times.
SAMPLE-YEARS	The default, specifies that the prior years corresponding to the Fibonacci sequence 1, 2, 3, 5, 8, 13, 21 … will be simulated, and weighted by the number of years that each represents. For example, if NUM-OF-YEARS = 15, then the following years will be simulated: 1, 2, 3, 5, 8, 13, 15 (the last year of the history is always simulated.)

The Fibonacci method recognizes that the majority of the change in well field response tends to occur in the early years, and that the later years tend to approach a steady state condition. Typically, this method will produce results within 1% - 2% of simulating ALL-YEARS, but can require considerably less run time.

SIZE-FIELD-MULT
Accepts the code words NO or YES to indicate whether ground-loop heat exchanger should be automatically sized based on a preliminary selection of well-field characteristics, and design-day data.

Sizing for a ground-loop heat exchanger is considerably more complex than other components; such as fans or chillers. The required capacity is not just a function of peak load, but also depends on the multi-year thermal balance of heating vs. cooling loads, optimal working temperatures, well configuration, well spacing, well depth, earth characteristics, etc. For this reason, it will usually be necessary for the user to conduct a multi-run study investigating various combinations of factors, and to review the results to determine the optimal configuration.

This keyword provides a starting point for the user's sizing optimization study. The method is as follows:

1. Select a CONFIGURATION that approximately represents the well field. For example, if the well field will most likely consist of two rows of wells, then "Rectangle-2x5" would be an appropriate choice. If the well field will have both exterior wells and interior wells (wells completely surrounded by other wells), then "Rectangle-4x4" might be appropriate. As this selection is simply the starting point, it is not critical what the actual selection is.

2. Specify SIZE-FIELD-MULT = YES. At the completion of the design-day simulations, the program will calculate the required number of bores based on the specified bore DEPTH, the maximum of the peak heating or cooling load, and assuming that each ton of cooling (or "ton" of heating) requires 250' of bore depth (21.6 M/kW).

   Based on the calculated number of bores, and the actual number of bores in the selected CONFIGURATION, the program will calculate the FIELD-MULTIPLIER; i.e. the number of identical well fields of the CONFIGURATION selected. (Note that, while FIELD-MULTIPLIER is user-input as an integer value, the autosizing calculation will use a real value.)

3. The annual simulation will then proceed. The required number of bores calculated will be displayed in the PS-H report for this component, and the annual thermal performance will be tabulated in the PS-O reports for the associated circulation-loop (one report for when the loop has a net heating load and one report for net cooling loads). Note that the temperatures in the PS-O reports are for the circulation-loop, and include the effect of any hybrid supplemental equipment such as a fluid cooler.

4. Based on the results above, the user should refine the selection of the CONFIGURATION, DEPTH, etc. (and FIELD-MULTIPLIER if more than one field will be required).

5. *After the starting-point simulations are complete, it is important that SIZE-FIELD-MULT be set to NO. Whenever SIZE-FIELD-MULT = YES, the program will calculate the FIELD-MULTIPLIER, overriding any user input or default input for this value, and effectively adjusting the size of the ground-loop heat exchanger.*

6. In subsequesnt iterations (with SIZE-FIELD-MULT = NO), review the temperature profiles in the PS-O reports, adjust the ground-loop or hybrid equipment parameters, and repeat the simulation until the optimal configuration is found.

7. During this iterative sizing process, it is possible that the circulation-loop's maximum or minimum alarm temperature limit may be exceeded, in which case the program will issue a message and terminate the simulation. This is a sign that the ground-loop heat exchanger is too small, or that a hybrid setup is required, or that the alarm limit may need to be relaxed.

CAPACITY

The rated capacity of the ground-loop heat exchanger. The program uses this value to calculate the design flow rate through the ground loop heat exchanger. This flow rate is then used hourly to adjust the pressure drop through the ground loop. If you don't specify this keyword the capacity will default to the loop capacity adjusted by the CAPACITY-RATIO. If no CAPACITY-RATIO is input the capacity will default to the loop capacity divided by the number of heat-exchangers attached to the loop.

Note that, if the keyword SIZE-FIELD-MULT = YES, then CAPACITY will be used in lieu of the design-day peak to adjust the number of trenches (horizontal), or the number of well fields (vertical).

CAPACITY-RATIO

When CAPACITY is not specified, this is the fraction of the design loop flow that this heat-exchanger will be sized to meet. If in addition, SIZE-FIELD-MULT = YES, then this is also the fraction of the design loop cooling or heating load (maximum of the two) to which this heat-exchanger will be sized.

DESIGN-HEAT-DAY
No longer used; replaced by annual initialization simulations, defined by HISTORY-SETUP.

DESIGN-COOL-DAY
No longer used; replaced by annual initialization simulations, defined by HISTORY-SETUP.

DESIGN-HEAT-LOAD
No longer used; replaced by annual initialization simulations, defined by HISTORY-SETUP.

DESIGN-COOL-LOAD
No longer used; replaced by annual initialization simulations, defined by HISTORY-SETUP.

BOILER

HW-SERIES-LOCN
If a hybrid system is specified consisting of a ground-loop heat exchanger and supplemental heating and/or cooling (boiler and/or heat-rejection), then the equipment is always assumed to be in series, with the ground-loop heat exchanger upstream of the supplemental equipment. In this case, this keyword is ignored.

HW-BYPASS-FLOW
Specifies the fraction of the total loop flow that will be conditioned by the boiler, but that is bypassed around the boiler rather than flowing through the boiler. The setpoint of the fluid flowing through the boiler will be increased to compensate for the bypassed flow, so that the temperature of the mixed fluid is at setpoint.

For a variable flow loop, at lower flows all of the fluid flows through the boiler. Once the loop flow exceeds the boiler's design flow, then the surplus flow is bypassed.

This feature was implemented for use in hybrid ground-loop heat exchanger systems, but is applicable to all situations. In the case of the hybrid GLHX system, the boiler provides supplemental heating to the loop, and may be sized to a significantly smaller flow than the loop flow. In this case, it may not be reasonable to force the entire loop flow through the boiler, as excessive head loss may result. If the boiler efficiency is sensitive to the leaving temperature (by default it is not), then the efficiency will be affected by the increase in leaving temperature.

CAPACITY-RATIO
If the boiler is to be default sized, specifies the fraction of the peak heating load that will be picked up by the boiler.

For hybrid ground-loop heat exchanger systems, the boiler (if used) and ground field are in series. For proper sizing of the fluid flow, the capacity ratios of the boiler and ground-loop heat exchanger should sum to at least 1.0.

CHILLER

Previously, chillers of TYPE = HEAT-PUMP or LOOP-TO-LOOP were required to reject/draw heat only from GROUND-LOOP-HXs of TYPE = LAKE/WELL. This restriction has been removed, and these chillers may attach to any WLHP system, including those served by closed ground-loop heat exchangers (such as VERT-WELL-NEW).

Note that CIRCULATION-LOOP:TYPE = LAKE/WELL has been eliminated; WLHP should be specified instead.

HEAT-REJECTION

CW-SERIES-LOCN

This keyword is inactive for heat-rejection devices; towers are always assumed to operate in parallel, except in the case where a tower co-exists with a ground-loop heat exchanger. In this case, the equipment is assumed to be in series, with the ground-loop heat exchanger upstream of the tower.

CW-BYPASS-FLOW

Specifies the fraction of the total loop flow that will be conditioned by this equipment, but that is bypassed around the equipment rather than flowing through the equipment. The setpoint of the fluid flowing through the equipment will be decreased to compensate for the bypassed flow, so that the temperature of the mixed fluid is at setpoint.

For a variable flow loop, at lower flows all of the fluid flows through the heat-rejection device. Once the loop flow exceeds the device's design flow, then the surplus flow is bypassed.

This feature was implemented for use in hybrid ground-loop heat exchanger systems, but is applicable to all situations. In the case of the hybrid GLHX system, a fluid cooler (or other heat-rejection device) provides supplemental cooling to the loop, and may be sized to a significantly smaller flow than the loop flow. In this case, it may not be reasonable to force the entire loop flow through the fluid cooler, as excessive head loss may result. Since the fluid cooler's performance is highly sensitive to the leaving temperature vs. the wetbulb temperature, then the efficacy will be affected by the decrease in setpoint temperature. For this reason, it may not make sense to specify very large bypass fraction.

For example, consider a ground loop heat exhanger system with a return temperature of 95°F (35°C), and a cooling setpoint of 85°F (29.5°C). If the bypass fraction is specified to be 0.6, then 60% of the loop flow will bypass the fluid cooler. To compensate, the temperature setpoint of the fluid cooler will have to be reduced to:

$$85°F = 0.6*95°F + (1-0.6)x$$
$$x = (85°F - 0.6*95°F) / (1-0.6) = 70°F (21.1°C)$$

To cool the fluid to 70°F will require more energy than cooling it to 85°F, and may be impossible depending on the wetbulb temperature.

CAPACITY-RATIO

If the heat-rejection device is to be default sized, specifies the fraction of the peak cooling load that will be picked up by this component.

For hybrid ground-loop heat exchanger systems, the heat-rejection device (if used) and ground field are in series. For proper sizing of the fluid flow, the capacity ratios of the two components should sum to at least 1.0.

DATA CENTER ENHANCEMENTS

Introduction

Data centers typically have equipment loads varying between 20 W/sq.ft. to over 150 W/sq.ft. Because these equipment loads dwarf the loads found in typical commercial facilities such as office buildings, data centers offer unique opportunities for achieving energy savings in the HVAC systems. Many existing technologies are already applicable to data center HVAC systems, such as economizers, and others are currently in research and development.

To facilitate the analysis of data centers, several new features have been incorporated into the program, including:

- Hot aisle / cold aisle simulation - conventional HVAC air distribution results in spaces in which the temperature is relatively uniform from floor to ceiling, and from side to side. In contrast, the equipment racks in data centers may be configured in rows, with the air intakes oriented to one row and the air exhaust to another row; creating cold aisles and hot aisles. Further, if all supply air is distributed to the cold aisles, and physical barriers constructed to reduce air circulation between the hot aisles and the cold aisles, then significant stratification may be achieved between the supply temperature introduced into the cold aisles, the average cold aisle temperature, and the return air temperature. This stratification can make economizers more effective, and can also enhance the performance of chilled-water coils or DX systems.

- Equipment sizing based on supply/return temperature differentials - For sizing airflows into a zone, the airflow is typically calculated based on the zone load, and the differential between the MIN-SUPPLY-T and the DESIGN-COOL-T. An alternative has been added to allow the differential to be directly specified.

- Multiple HVAC systems serving the same zone - Data centers typically have more than one HVAC unit serving the same space. The program has been enhanced to allow multiple identical HVAC systems to serve the same zone. Units may be either all run in parallel, or may be staged on/off according to the load.

- Thermostat location - The ability to specify whether the zone thermostat is located in the zone (measuring average cold aisle temperature), or in the return air.

- A new cooling tower control strategy - Because data centers typically operate with a cooling load 24 hours per day, and new control scheme has been implemented to allow the cooling tower temperature setpoint to be reset based on wetbulb temperature.

- Waterside economizer - This version of the program supports a waterside economzer fully integrated into the chilled water loop. The waterside economizer is upstream of the chillers, and precools the return water prior to entry into the chillers. This feature is presented in a separate section in this document, "CHW-Loop Economizer Cooling".

- Underfloor air distribution supply plenums served by single-zone systems - Data centers often have the supply air delivered via an underfloor supply plenum. Previously, the program could simulate underfloor supply plenums for single duct systems such as variable-air volume systems with multiple zones. This capability has been extended to single zone systems such as SZRH and PVVT; systems which are typically used in data centers. Underfloor air distribution is discussed in a separate section, "Underfloor HVAC Air Distribution".

Building Description Language Changes

The following keywords were implemented to facilitate the analysis of data centers. However, they may be applicable to many other uses.

SPACE

A keyword has been added to allow the dynamics of hot aisles and cold aisles to be simulated. When a hot/cold aisle design is implemented in a data center, the HVAC units are typically controlled via multiple sensors located in the space. The equipment may be controlled on the basis of either the average temperature of all sensors, the maximum temperature, or some other relationship between the sensors.

A new keyword, EQUIP-TO-RETURN, has been added that is similar to LIGHT-TO-RETURN. It defines the fraction of the equipment heat gain that does not affect the average space temperature, but instead flows directly into the return. If measurements are made in a data center of supply temperature, return temperature, and average rack inlet temperature, the fraction of heat flowing directly to the return is calculated as:

$$FracReturn = (Tret - Tzone) / (Tret - Tsup)$$

where

Tzone	the rack inlet temperature, averaged over all racks; corresponds to COOL-TEMP-SCH
Tret	the temperature of the air leaving the hot aisles, returning to the HVAC system(s)
Tsup	the temperature of the air entering the cold aisles

EQUIP-TO-RETURN
Takes a list of values, for up to five equipment types, of the fraction of equipment heat that goes directly to the return air stream, and does not affect the average space temperature seen by the thermostat. Unless the zone is configured so that return air passes through the equipment (such as in many data center configurations), EQUIP-TO-RETURN should be allowed to default to zero.

This fraction applies to both the sensible and latent equipment heat gains. For example, if EQUIPMENT-KW = 1.0, EQUIP-SENSIBLE = 0.70, EQUIP-LATENT = 0.30, and EQUIP-TO-RETURN = 0.2, then 1.0 * 0.70 * 0.20 = 0.14 kW will flow to the return as sensible heat, and 1.0 * 0.30 * 0.20 = 0.06 kW will flow to the return as latent heat.

Note that, unlike LIGHT-TO-RETURN, there is no "equip-to-space" or "equip-to-other". All equipment heat that is not captured in the return airflow is assumed to go to the space.

For variable-volume zones, the fraction of equipment heat captured in the return airflow drops as the airflow drops (otherwise the temperature rise in the return air would approach infinity as the return flow approaches zero). The program assumes that the fraction of heat captured in the return varies as the square root of the airflow ratio. For example, if the hourly airflow ratio is 0.15 of maximum, then the heat captured in the return is $(0.15)^{0.5} = 38\%$ of the heat captured at full airflow.

SYSTEM
COOL-SUP/RET-DT
Specifies the design differential between the zonal supply and return temperatures for zone airflow sizing calculations when a zone is in the cooling mode. When specified, this keyword takes precedence over the MIN-SUPPLY-T, hourly zone temperature, or other combinations of values; the zonal heating airflow is a function of this differential and the extraction load.

This keyword has an identical keyword within the ZONE command. The default of the zonal keyword is the value specified at the SYSTEM level. At the zone level, this keyword overrides other temperatures, but does not override any user-defined airflows.

Coupled with SIZING-METHOD = CAPACITY/FLOW, and setting the FLOW/CAPACITY in the range of 550 cfm will cause the data center HVAC system(s) to be sized to the temperature differential, rather than the equipment load. This is useful in the analysis of data centers which have poor air management. For example, if a data center is measured and found to have only a 15°F differential between the supply and return temperatures, then setting the COOL-SUP/RET-DT = 15 will cause the air handler fans and compressors to both be sized larger than what is actually needed to satisfy the load.

HEAT-SUP/RET-DT

(not applicable to data centers, but included for symmetry with cooling) Specifies the design differential between the zonal supply and return temperatures for zone airflow sizing calculations, when a zone is in the heating mode. When specified, this keyword takes precedence over the MAX-SUPPLY-T, REHEAT-DELTA-T, hourly zone temperature, or other combinations of values; the zonal heating airflow is a function of this differential and the extraction load.

This keyword has an identical keyword within the ZONE command. The default of the zonal keyword is the value specified at the SYSTEM level. At the zone level, this keyword overrides other temperatures, but does not override any user-defined airflows.

NUMBER-OF-UNITS

Specifies the number of identical air handlers that serve the load. This keyword is not applicable for zonal systems such as fan coils (FC) or water-loop heat pumps (HP). This keyword has a different meanings depending on whether the system being modeled is a floor-by-floor system, or whether multiple systems serve a single zone.

For a floor-by-floor system, the FLOOR:MULTIPLIER is typically used to define multiple identical floors in a high rise. If a SYSTEM is defined for this group of floors (or one or more zones on the floor), by default the program assumes that *all* of the floors are served by a *single* air handler. To model an air handler serving each floor, specify the SYSTEM:NUMBER-OF-UNITS and set the value to be the same as the FLOOR:MULTIPLIER. The zone loads will then be divided among the air handlers. If an air handler serves every two floors, then set the NUMBER-OF-UNITS to be one-half of the floor multiplier, etc. Other configurations are also supported; the loads and airflows of whatever zones are in the system are divided among the NUMBER-OF-UNITS.

For data centers or other applications where multiple identical air handlers serve a single zone, the NUMBER-OF-UNITS defines the number of identical air handlers serving the space. In this mode, the UNIT-STAGING defines whether the air handlers run in parallel, or whether they stage sequentially as the loads vary.

For all cases, the SUPPLY-FLOW, COOLING-CAPACITY, etc. are defined for a *single* air handler. Air handler quantities in report SV-A are also reported for a single air handler. Monthly and annual simulation results are reported for all air handlers. Hourly report values are typically for a single air handler.

UNIT-STAGING

For data centers or other applications where multiple identical air handlers serve a single zone, defines whether the air handlers are loaded in parallel, or whether units are staged sequentially with load. This keyword applies only to the single-zone systems SZRH, PSZ, PVVT and EVAP-COOL.

PARALLEL   The default, specifies that all units run simultaneously and the load is divided evenly between all units.

SEQUENTIAL	Specifies that units are staged sequentially as the zone load varies. The load is divided evenly between the units that are running in a given hour.

ECONO-MIN-DEWPT

for all economizer types, specifies a minimum outdoor-air dewpoint below which the outside air dampers return to their minimum position. If not specified, there is no minimum allowable dewpoint temperature.

This feature can prevent excessively low humidity levels in buildings located in very cold or dry climates, and may be especially useful when humidifiers are used. Oftentimes, the energy saved by using an economizer may be more than offset by the energy consumed in re-humidifying very dry air.

SUPPLY-PLENUM

Accepts the U-name of a plenum zone belonging to the same system. While a plenum normally transports return air, the program will use this plenum to supply air to all of the zones in the system. Only one supply plenum is allowed per system, but a system may have any additional number of return plenums. The user should refer to the section "Underfloor HVAC Air Distribution" in this document for more information.

Note that, while underfloor supply plenums are common in data centers, the heat gain/losses in the underfloor supply plenum are typically a very small fraction of the total loads in the data center; the equipment rack heat gains may be 100 times larger. For this reason, underfloor supply plenums may often omitted from the model without a significant impact on energy savings.

ZONE

COOL-SUP/RET-DT

This keyword has the same meaning as the identical keyword at the SYSTEM level, and defaults to the system level value.

HEAT-SUP/RET-DT

This keyword has the same meaning as the identical keyword at the SYSTEM level, and defaults to the system level value.

THERMOSTAT-LOCN

For conditioned zones, specifies the location of the zone's thermostat:

WITHIN-ZONE	the default, specifies that the thermostat is located within the zone.
ZONE-RETURN	specifies that the thermostat is located in the zone's return airflow. While unusual for most systems, this location may be used for air handlers serving data centers.

Unless the zone has heat gains that go directly into the return air (SPACE:LIGHT-TO-RETURN, SPACE:EQUIP-TO-RETURN, ZONE:PLUME-***, ZONE:DIFFUSER-LOSS-***), the zone return air temperature will be the same as the zone temperature (fully mixed airflow), and this keyword is irrelevant. But if the zone has heat gains/losses that are captured by the return airflow, then the return air temperature may be either greater or lesser than the zone temperature. The zone heating and cooling thermostat schedules should reflect the location of the thermostat. The same is also true for the DESIGN-HEAT-T and DESIGN-COOL-T.

When the thermostat is located in the zone return, the fan must run continuously during occupied hours (SYSTEM:INDOOR-FAN-MODE = CONTINUOUS); otherwise the return air temperature cannot be sensed. The program will issue an error if the indoor fan is allowed to cycle.

CIRCULATION-LOOP

The following loop temperature control strategy has been added for cooling towers. This allows a tower to take advantage of low wetbulb temperatures when they are available, while avoiding excessive fan energy when the wetbulb temperature is higher.

COOL-SETPT-CTRL

Code word specifies the loop temperature control sequence:

WETBULB-RESET   For CW and WLHP loops only, specifies that the loop temperature cooling setpoint is reset according to the outdoor wetbulb temperature, plus an offset. The offset may be either fixed, or may vary with the wetbulb. See the keywords COOL-SETPT-T, CW-AMBIENT-DT and WETBULB-RATIO for more information.

CW-AMBIENT-DT

For COOL-SETPT-CTRL = WETBULB-RESET (applicable only to the cooling setpoint for CW and WLHP loops), specifies the differential between the hourly cooling setpoint and the wetbulb.

As the hourly wetbulb varies, the setpoint is calculated as

TargetWB   = COOL-SETPT-T – CW-AMBIENT-DT   (fixed all hours)
dTsetpt   = CW-AMBIENT-DT + [(TargetWB - HourlyWB) * WETBULB-RATIO]
Tsetpt   = HourlyWB + dTsetpt

The default for WETBULB-RATIO is 0.28, which recognizes that, as the wetbulb drops, the tower capacity for a given approach to the wetbulb also drops; for a given load, a tower cannot achieve the same approach to wetbulb as it can at higher wetbulbs. To track the wetbulb using a fixed differential, specify WETBULB-RATIO = 0.

WETBULB-RATIO

For COOL-SETPT-CTRL = WETBULB-RESET (applicable only to the cooling setpoint for CW and WLHP loops), modifies the CW-AMBIENT-DT as the wetbulb varies.

As the hourly wetbulb varies, the setpoint is calculated as

TargetWB   = COOL-SETPT-T – CW-AMBIENT-DT   (fixed all hours)
dTsetpt   = CW-AMBIENT-DT + [(TargetWB - HourlyWB) * WETBULB-RATIO]
Tsetpt   = HourlyWB + dTsetpt

The default for WETBULB-RATIO is 0.28, which recognizes that, as the wetbulb drops, the tower capacity for a given approach to the wetbulb also drops; for a given load, a tower cannot achieve the same approach to wetbulb as it can at higher wetbulbs. To track the wetbulb using a fixed differential, specify WETBULB-RATIO = 0.

DESIGN-SIZING ENHANCEMENTS

Introduction

The power of the design sizing routines have been expanded to better calculate coincident loads on airhandlers and central plant equipment. In DOE-2.3 and earlier versions, the design sizing sequence was:

- <u>LOADS</u> – the LOADS module ran it design-sizing calculations, and then ran through the rest of the simulation period(s). Design-sizing information was passed to the HVAC module for use in equipment sizing calculations.

- <u>Zonal equipment</u> – the airside HVAC module used the loads design-sizing data to size zonal coils and airflows.

- <u>Central airhandlers</u> – the size of the air handler was set to the sum of the zonal airlflows, without taking any diversity into effect (exception: buildings with only one air handler could size to the coincident zone load; however this sizing could not take into account the effect minimum flow ratios in various zones.)

- <u>Waterside equipment</u> – boiler, chillers etc. were sized based on the sum of the attached coils, without taking any diversity into effect. This typically resulted in boilers and chillers that were significantly oversized.

- <u>HVAC design-sizing run periods</u> – while a design-sizing run was made for the HVAC equipment, the results of this run were ignored, as all equipment was already sized.

Now the program makes several passes through the design-sizing run periods (or annual weather if design days are not specified), so that coincident sizing can be properly assessed:

- <u>LOADS</u> – As before, the LOADS module runs it design-sizing calculations, and then runs through the rest of the simulation period(s). Design-sizing information is passed to the HVAC module for use in equipment sizing calculations.

- <u>Zone airflows</u> – Next, all equipment is simulated using the heating design-day and cooling design day schedules, fan schedules, and thermostat schedules. Zone airflows are determined, taking into account the effect of startup loads (loads due to startup temperature changes in the spaces), and interactions between zones at different temperatures.

  For example, unconditioned zones or plenums separated from conditioned zones via ceiling tiles may result in significant heat transfer during peak heating and cooling periods. Previously, the ZONE:SIZING-OPTION = ADJUST-LOADS attempted to take interzonal heat transfer into account, but relied upon the user's educated guesses of unconditioned zone temperatures as specified in the DESIGN-HEAT-T and DESIGN-COOL-T values for those zones. This technique is no longer necessary, or allowed. Instead, all zones are simulated over the design-day periods, and the hourly temperatures of all zones are explicitly calculated; taking into account the hourly thermal interactions of those zones. In this manner, the design airflows can be determined with greater precision than before.

- <u>Air handler airflows and coil capacities</u> – Once the zone terminal airflows are sized, the design-day simulations are repeated a second time to determine the coincident airflows at each air handler, and the coincident coil loads at both the air handler (heating and cooling coils) and at the zone (reheat coils,

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baseboards, etc.); taking both zone diversity and coincident outside ventilation air requirements into account.

- <u>Boilers, chillers, etc. equipment</u> – Once the central air handlers and coils are sized, and if circulation loops and attached equipment are specified, then the design-day simulations are repeated again to determine the coincident loads on boilers and chillers; together with the associated temperatures and flows.

- <u>Cooling towers</u> - If cooling towers are specified, then once the water-cooled chiller size(s) are known the design-day calculations are repeated again to determine the cooling tower sizes and coincident weather conditions.

- <u>Circulation loops, pumps</u> – A final design-sizing run is made to determine loop capacities, and the head and flow requirements on the pumps.

<u>Unsupported Features</u>

This beta version of the program is still in development, and involves substantial restructuring of the airside algorithms. At this time, not all features that exist in previous versions have been ported into the new structure utilized in this version. Keywords for unported features still exist in eQUEST, but they will be set to "unused" until implemented in this version. The Dictionary and other documentation may also still reference these unused features.

The following is a summary of features that are not available in this version

<u>*SPACE*</u>

- <u>Sunspaces</u> - The SUNSPACE keyword is forced to have the value NO.

- <u>Trombe Walls</u>

<u>*SYSTEM*</u>

- <u>System Types</u> - Not all system TYPEs are implemented. PTAC, HVSYS, EVAP-COOL, FPH and SUM will be implemented in future releases. RESVVT and SZCI may be implemented depending on user interest. RESYS will not be implemented, as it has been replaced by RESYS2. PTGSD has significant problems in the existing algorithm and will not be implemented until it is redeveloped. FNSYS1 may be implemented if user functions are implemented; otherwise it serves no purpose.

- <u>Gas Heat Pumps</u> - In HEAT-SOURCE, the codewords GAS-HEAT-PUMP and GAS-HYDRONIC have been removed. Currently no manufacturer is known to make engine-driven heat pumps, so this feature may be permanently eliminated. This is true for ZONE-HEAT-SOURCE and PREHEAT-SOURCE as well.

- <u>Two speed fans</u> - In FAN-CONTROL, the codeword TWO-SPEED is currently not implemented. However, the PVVT system type supported AIR/TEMP-CONTROL = TWO-SPEED which is a better implementation of this feature.

- <u>Dessicant Systems</u> - The desiccant system type, as well as the add-on desiccant dehumidifier on the outside air, are disabled. Additional research will be required to properly implement these systems.

- <u>Waterside economizers</u> - The waterside economizer that works in conjunction with a water-cooled DX unit is not currently implemented (WS-ECONO and related keywords). However, the waterside economizer that operates at the central plant level is implemented, and contains additional features.

- <u>Energy Recovery Ventilators</u> - The energy recovery ventilator is not currently implemented (RECOVER-EXHAUST and related keywords).

- <u>Night Ventilation</u> - Night ventilation, i.e. the operation of the main system fans in a reduced airflow mode to precool the building, is not currently implemented (NIGHT-VENT-CTRL and related keywords).

- <u>Optimum Start</u> – is not currently implemented.

- <u>Compressor Type</u> - This feature is not currently implemented (COMPRESSOR-TYPE). To model two-speed or variable-speed compressors, the performance should be imbedded in the part-load curve.

- <u>Evaporative Coolers</u> - The evaporative cooler system type, as well as the outdoor air evaporative precooler, is not currently implemented (EVAP-CL-TYPE and related keywords).

- <u>Outdoor Air from another System</u> - The OA-FROM-SYS feature is not currently implemented. The intent is to supplement or replace this capability with a new dedicated outdoor air system type.

ZONE

- <u>Ice Rinks</u> - This feature is not currently implemented (ICE-RINK and related keywords). This feature will be best implemented when desiccant systems are also implemented. In addition, it will require the use of a new system type that controls the desiccant system on the basis of zone humidity, rather than zone temperature (previous versions of the program allowed the desiccant system to run on the basis of the zone thermostat which enabled the fan. In reality, desiccant dehumidifiers serving ice rinks are controlled on the basis of relative humidity, not temperature.)

Building Description Language Changes

There are numerous minor changes to many of the HVAC components.

SYSTEM

SIZING-OPTION

Takes a code-word that specifies whether the system's SUPPLY-FLOW equals the sum of the zone flows (NON-COINCIDENT) or is based on the peak block load (COINCIDENT). If the number of hours with "loads not met" is too high with SIZING-OPTION = NON-COINCIDENT, you should increase the air-side system capacity by setting SIZING-RATIO > 1.0.

NON-COINCIDENT	SUPPLY-FLOW is sized using the sum of the design airflows of the individual zones. (These peaks usually occur at different times and are, therefore, non-coincident.)
COINCIDENT	SUPPLY-FLOW is sized using the peak value of the sum of the airflows of the zones on the system.

SIZING-RATIO

Multiplier on the program-calculated values of air handler airflow and coil capacities, zonal airflow and coil capacities, zonal baseboards, and and central plant equipment.. This keyword is used to deliberately oversize or undersize the equipment in the system. The input for this keyword is the desired capacity of the system divided by either (1) the capacity you assign in the secondary systems input or (2) the capacity calculated by the program from peak loads. SIZING-RATIO does not modify the heating/cooling loads calculated in LOADS. It modifies both the

terminal and AHU sizing, as well as the central plant equipment. If you want to increase the central plant equipment sizing only, use the sizing keywords within those components. Using SIZING-RATIO will probably change the responsiveness of the system, making it faster or slower depending on whether you oversize or undersize the equipment.

Note that SIZING-RATIO increases airflows, coil capacities, and all downstream central plant equipment. COOL-SIZING-RATI (see below) does not increase airflow, but increases coil capacity and downstream central plant equipment. If both keywords are specified, the net multiplier is the product of the keywords.

Air Flow and Fans

The following keywords provide information on system supply air flow rates, fan power , and fan control. You may specify air flows at either standard or actual conditions. Standard conditions are defined as sea level (29.921" Hg), 70°F and dry air. Actual conditions are also assumed to be 70°F and dry air, but adjusted for the building's altitude.

In the case of a zonal system, the keywords apply to *each* zone. For example, if the SUPPLY-FLOW is 2000 cfm, then each zone is assumed to receive 2000 cfm. For central systems, the keywords apply to the central system; flows, etc. may be further broken down at the ZONE level.

SUPPLY-FLOW

The design capacity of the system's air supply fan. This entry is usually omitted, unless fan capacity is a known value and different from the air flow rates calculated by the program . The program calculates the default from zone loads and ZONE command input. If SITE-PARAMETERS:SPECIFY-AIRFLOWS = SEA-LEVEL, then this flow is assumed to be at sea-level, and will be corrected to the equivalent airflow at the actual building altitude.

For a zonal system where the system creates a separate air handler for each zone (UVT, UHT, FC, HP, PTAC), this will be the supply flow for each zonal air handler. You may modify this value at the zonal level using the ZONE:ASSIGNED-FLOW keyword.

You will improve the simulation accuracy for existing buildings by inputting known system SUPPLY-FLOW.

If the SUPPLY-FLOW is larger than the design supply flow, the program proportions the specified total supply air into zone air quantities as follows:

Adjusted Zone Air Flow =

$$\left(\frac{<SUPPLY-FLOW>}{(\text{Sum of Calculated Zone Air Flows})}\right)*\left(\text{Calculated Zone Air Flow}\right)$$

If the SUPPLY-FLOW is less than the design supply flow, the design zone airflows are not re-apportioned, as diversity may exist between variable-volume terminals. However, the reduced supply flow will be taken into account hourly, and the maximum flow limited to each zone if the zones demand more than the airhandler can supply.

SIZING-METHOD

DEFAULT — The program calculates the cooling capacity and supply airflow, but does not explicitly link one to the other. Note that the user may specify either the COOLING-CAPACITY or the SUPPLY-FLOW to override the default calculation.

If the MAX-FLOW/CAPACITY is specified, this keyword will act as an upper limit on the airflow/capacity ratio. If the airflow is greater than allowed by this limit, the capacity will be increased. Similarly, if the MIN-FLOW/CAPACITY is

specified, this keyword will act as a lower limit on the airflow/capacity ratio. If the capacity is greater than allowed by this limit, the airflow will be increased.

FLOW/CAPACITY
The program calculates the default cooling capacity, and uses it to set the supply airflow. If the user specifies the COOLING-CAPACITY, this value will be used to set the airflow.

If neither the MAX-FLOW/CAPACITY or the MIN-FLOW-CAPACITY is specified, then the airflow will be sized to the rated capacity, multiplied by the FLOW/CAPACITY. For example, if the rated capacity is 10 tons (120 kBtu) and the FLOW/CAPACITY = 400 cfm/ton, then the coil flow is 10 tons * 400 cfm/ton = 4,000 cfm.

If either the MAX-FLOW-CAPACITY or MIN-FLOW/CAPACITY is specified, then the FLOW/CAPACITY is ignored. Instead, the airflow is limited to the airflow range defined by these keywords. For example, if the rated capacity is 10 tons (120 kBtu), the MAX-FLOW/CAPACITY = 500 cfm/ton, and the MIN-FLOW/CAPACITY = 300 ton, then the allowable airflow range is 5,000-3,000 cfm. The actual airflow will be the default airflow, limited to this range.

CAPACITY/FLOW
The program calculates the default supply airflow, and uses it to set the cooling capacity. If the user specifies the SUPPLY-FLOW, this value will be used to set the cooling capacity.

If neither the MAX-FLOW/CAPACITY or the MIN-FLOW-CAPACITY is specified, then the cooling capacity will be sized to the rated airflow, divided by the FLOW/CAPACITY. For example, if the rated airflow is 4,000 cfm and the FLOW/CAPACITY = 400 cfm/ton, then the rated capacity will be 4,000 cfm / 400 cfm/ton = 10 tons (120 kBtu).

If either the MAX-FLOW-CAPACITY or MIN-FLOW/CAPACITY is specified, then the FLOW/CAPACITY is ignored. Instead, the cooling capacity is limited to the capacity range defined by these keywords. For example, if the program defaults the rated airflow to 4,000 cfm, the MAX-FLOW/CAPACITY = 500 cfm/ton, and the MIN-FLOW/CAPACITY = 300 ton, then the allowable capacity range is 8-13.33 tons (96-160 kBtu). The actual capacity will be the default capacity, limited to this range.

FLOW/CAPACITY

is the ratio of the coil airflow to the coil capacity at the rated conditions. This keyword specifies the rating point of the coil bypass factor, COIL-BF. Note that this keyword is always specified at sea level. For other flowrates (including adjustments for altitude), the coil bypass factor will be adjusted accordingly.

If the coil SIZING-METHOD = FLOW/CAPACITY, and neither the MAX-FLOW/CAPACITY or the MIN-FLOW/CAPACITY is specified, then the coil airflow will be sized as:

Airflow (cfm) = Rated capacity (Btuh) / 12000 Btu/ton * FLOW/CAPACITY

FLOW-CAPACITY is assumed to be at sea level, and the calculated airflow will be further adjusted for altitude. (The coil bypass factor is also at sea level, and an altitude adjustment for airflow will result in an adjustment for coil bypass.) Similarly, if the coil SIZING-METHOD = CAPACITY/FLOW, and neither the MAX-

FLOW/CAPACITY or the MIN-FLOW/CAPACITY is specified, then the coil capacity will be sized as (also adjusted for altitude):

Capacity (Btuh) = Airflow (cfm) / FLOW/CAPACITY * 12000 Btu/ton

MIN-FLOW/CAPACITY
specifies the lower limit on the ratio of coil airflow to rated capacity. This keyword is not adjusted for altitude.

If the coil SIZING-METHOD = DEFAULT, and the ratio of the default airflow/capacity is less than this limit, then the default airflow will be increased to match the limit. For example, if the default design capacity is 10 tons, with a corresponding airflow of 2000 cfm, the ratio is 2000/10 = 200 cfm/ton. If this keyword specifies an lower limit of 250 cfm/ton, then the default ratio os below this limit; the rated airflow will be increased to 10 tons * 250 cfm/ton = 2500 cfm to match this limit.

If the coil SIZING-METHOD = FLOW/CAPACITY or CAPACITY/FLOW, and this keyword is specified, then this keyword will act as a limit on the default sizing. Refer to the SIZING-METHOD for examples.

MAX-FLOW/CAPACITY
specifies the upper limit on the ratio of coil airflow to rated capacity. Note that this keyword is not adjusted for altitude. For high-altitude conditions, you might increase this value; however the maximum flow is often a function of coil moisture carryover which is primarily a function of air velocity rather than density.

If the coil SIZING-METHOD = DEFAULT, and the ratio of the default airflow/capacity is greater than this limit, then the default capacity will be increased to match the limit. For example, if the default design airflow is 10,000 cfm with a corresponding capacity of 16.67 tons, the ratio is 10000/16.67 = 600 cfm/ton. If this keyword specifies an upper limit of 500 cfm/ton, then the default ratio exceeds this limit; the rated tonnage will be increased to 10000cfm/500 cfm/ton = 20 tons (240 kBtu) to match this limit.

If the coil SIZING-METHOD = FLOW/CAPACITY or CAPACITY/FLOW, and this keyword is specified, then this keyword will act as a limit on the default sizing. Refer to the SIZING-METHOD for examples.

SUPPLY-EFF
No longer required. If specified, then the SUPPLY-MTR-EFF is calculated as a function of this value and the SUPPLY-MECH-EFF. It is recommended that this keyword be omitted, and either the SUPPLY-MTR-EFF or SUPPLY-MTR-CLASS be specified instead.SUPPLY-DELTA-T

SUPPLY-DELTA-T
No longer used; see SUPPLY-MECH-EFF and SUPPLY-MTR-EFF.

SUPPLY-KW/FLOW
Design full-load power of the supply fan per unit of supply air flow rate. If SITE-PARAMETERS:SPECIFY-AIRFLOWS = SEA-LEVEL, then this quantity is specified at sea level; otherwise it is at the actual building altitude. Use either SUPPLY-STATIC or SUPPLY-KW/FLOW. For systems for which the FAN-PLACEMENT can be specified, and the placement is BLOW-THROUGH, the default value is increased by a factor of 1.11

SUPPLY-MECH-EFF
The mechanical efficiency of the supply fan. SUPPLY-MECH-EFF is used in conjunction with SUPPLY-STATIC and SUPPLY-MTR-EFF to calculate the fan power. The SYSTEMS program separates the total fan efficiency into its mechanical and electrical components. The mechanical energy loss of the fan is always added to the air stream. The electrical energy loss of the fan is added to the air stream only if the fan motor is located inside the air stream.

For systems in which the FAN-PLACEMENT can be specified, and the placement is BLOW-THROUGH, the program adjusts the default mechanical efficiency by 0.89 times its DRAW-THROUGH value.

SUPPLY-MTR-EFF
The efficiency of the supply fan motor. If not specified, the efficiency will default based on the design brake horsepower of the motor and the efficiency classification of the motor; specified by SUPPLY-MTR-CLASS.

SUPPLY-MTR-CLASS
specifies the motor class (efficiency) of the HVAC supply fan. Acceptable entries are:

STANDARD	specifies a standard motor.
HI-EFF	specifies a NEMA high efficiency motor.
PREMIUM	specifies a NEMA premium efficiency motor. A table presenting motor efficiency vs. motor size and class can be found in the PUMP:MOTOR-CLASS description.

HSUPPLY-FLOW
Same as SUPPLY-FLOW, except applies only to the heating fan when DDS-TYPE = DUAL-FAN. If not specified, the hot deck fan will be sized to meet the peak heating air flow rate. If all of the zone thermostats are REVERSE-ACTION, or the zone mixing boxes are constant-volume, then the hot-deck fan will be the same size as the cold-deck fan. If SITE-PARAMETERS:SPECIFY-AIRFLOWS = SEA-LEVEL, then this flow is assumed to be at sea-level, and will be corrected to the equivalent airflow at the actual building altitude.

HSUPPLY-EFF
No longer required. If specified, then the HSUPPLY-MTR-EFF is calculated as a function of this value and the HSUPPLY-MECH-EFF. It is recommended that this keyword be omitted, and either the HSUPPLY-MTR-EFF or HSUPPLY-MTR-CLASS be specified instead.SUPPLY-DELTA-T

HSUPPLY-DT
No longer used; see HSUPPLY-MECH-EFF and HSUPPLY-MTR-EFF.

HSUPPLY-KW/FLOW
For the hot-deck fan in a dual-fan dual-duct system (SYSTEM:DDS-TYPE = DUAL-FAN), specifies the design full-load power of the fan per unit of air flow rate. If SITE-PARAMETERS:SPECIFY-AIRFLOWS = SEA-LEVEL, then this quantity is specified at sea level; otherwise it is at the actual building altitude. Use either HSUPPLY-STATIC or HSUPPLY-KW/FLOW.

HSUPPLY-MECH-EFF
The mechanical efficiency of the hot-deck fan in a dual-fan dual-duct system (SYSTEM:DDS-TYPE = DUAL-FAN). Used in conjunction with HSUPPLY-STATIC and HSUPPLY-MTR-EFF to calculate the fan power. The default mechanical efficiency will be multiplied by a factor of 0.89 if the HFAN-PLACEMENT = BLOW-THROUGH

HSUPPLY-MTR-EFF
The efficiency of the hot-deck fan motor. If not specified, the efficiency will default based on the design brake horsepower of the motor and the efficiency classification of the motor; specified by FAN-MOTOR-CLASS.

HSUPPLY-MTR-CLAS
specifies the motor class (efficiency) of the HVAC hot deck fan. Acceptable entries are:

STANDARD	specifies a standard motor.

HI-EFF   specifies a NEMA high efficiency motor.

PREMIUM   specifies a NEMA premium efficiency motor. A table presenting motor efficiency vs. motor size and class can be found in the PUMP:MOTOR-CLASS description.

RETURN-FLOW

Design capacity (in standard, or sea level, flow) of the system's return air fan. If SITE-PARAMETERS:SPECIFY-AIRFLOWS = SEA-LEVEL, then this flow is assumed to be at sea-level, and will be corrected to the equivalent airflow at the actual building altitude.

The default for RETURN-FLOW is calculated from ZONE input and zone loads. Zonal exhaust flows may reduce the return flow.

If the RETURN-FLOW is specified to be less than the SUPPLY-FLOW, then the differential is assumed to exfiltrate and is lost whenever the hourly supply flow is greater than the RETURN-FLOW . Airflow at the outside air intake will be increased as necessary.

To pressurize the building using a constant differential between supply flow and return flow, specify the RETURN-CAP-RATIO; refer to that keyword for more details.

RETURN-EFF

No longer required. If specified, then the RETURN -MTR-EFF is calculated as a function of this value and the RETURN -MECH-EFF. It is recommended that this keyword be omitted, and either the RETURN -MTR-EFF or RETURN -MTR-CLASS be specified instead.

RETURN-DELTA-T

No longer used; see RETURN-MECH-EFF and RETURN-MTR-EFF

RETURN-KW/FLOW

The design full load power consumption of the return fan per unit of air flow at sea level. Use either RETURN-STATIC or RETURN-KW/FLOW.

RETURN-MECH-EFF

The mechanical efficiency of the return or relief fan. Used in conjunction with RETURN-STATIC and RETURN-MTR-EFF to calculate the fan power.

RETURN-MTR-EFF

The efficiency of the return or relief fan motor. If not specified, the efficiency will default based on the design brake horsepower of the motor and the efficiency classification of the motor; specified by FAN-MOTOR-CLASS.

RETURN-MTR-CLASS

specifies the motor class (efficiency) of the HVAC return fan. Acceptable entries are:

STANDARD   specifies a standard motor.

HI-EFF   specifies a NEMA high efficiency motor.

PREMIUM   specifies a NEMA premium efficiency motor. A table presenting motor efficiency vs. motor size and class can be found in the PUMP:MOTOR-CLASS description.

DUCT-DT
The average duct temperature rise when delivering cooled air at the design cooling airflow and the DUCT-ENVIR-DT; the differential between the supply temperature entering the duct and the duct's environment. Applies to all single-duct systems and to the cold duct of a dual-duct system. The value represents the average temperature rise of all air delivered. In actual systems, zones further from the air handler (on longer duct runs) will normally experience larger losses than zones closer to the air handler. Therefore, larger air flows will be required to make up the difference. This effect is not explicitly modeled.

DUCT-ENVIR-DT
When the DUCT-DT is specified, specifies the differential between the air temperature entering the duct (MIN-SUPPLY-T), and the duct's environment. This value, together with the DUCT-DT and the design airflow, is used to calculate the effective UA product of the duct. Alternatively, the DUCT-UA may be specified directly.

ZONE-OA-METHOD
Accecpts a code word describing how the zonal design outdoor air requirement is calculated.

MAX-OCC-OR-AREA	the default, indicates that each zone's outside air requirement is calculated as the MAXIMUM of the occupant-based ventilation or the area-based ventilation. This is consistent with many codes such as California's Title 24. It is not consistent with ASHRAE Standard 62.1 (see SUM-OCC-AND-AREA). Regardless, either method can produce the same result as long as input is modified according to the method.
SUM-OCC-AND-AREA	specifies that each zone's outside air requirement is calculated as the SUM of the occupancy-based ventilation and the area-based ventilation. This is consistent with ASHRAE Standard 62.1, but is not consistent with other codes such as California's Title 24 (see MAX-OCC-OR-AREA). Regardless, either method can produce the same result as long as input is modified according to the method.

The occupant-based ventilation rate is specified by OA-FLOW/PER (times the NUMBER-OF-PEOPLE). The area-based airflow is either the OUTSIDE-AIR-FLOW if specified; or the maximum of OA-CHANGES (times the zone VOLUME/60) or OA-FLOW/AREA (times the zone AREA).
If demand-controlled ventilation is used, then regardless of whether the occupancy-based or area-based ventilation rate is the design maximum, the result is adjusted hourly by the PEOPLE-SCHEDULE for use in the DCV controller. This assumes that the DCV controller is CO2 based. However, the area-based quantity, if specified, will also be used as the minimum allowable outside air quantity at the air handler (unadjusted for the people schedule). This ensures that CO2-based sensors cannot reduce the flow to below what is required to dilute building-generated pollutants.

Either method (maximum or sum) can produce the same result as long as input is modified according to the method. For example if ASHRAE specifies 5 cfm/person, 0.06 cfm/sq.ft, and an occupant density of 200 sq.ft./person, then the following gives equivalent results:

ASHRAE (using SUM-OCC-AND-AREA)
      OA-FLOW/PER   = 5
      OA-FLOW/AREA   = 0.06

Title 24 (using MAX-FLOW-OR-AREA)
      OA-FLOW/PER   = 17
      OA-FLOW/AREA   = 0.06

These two methods are equivalent because:

5 cfm/person + 0.06 cfm/sq.ft. * 200 sq.ft./person = 17 cfm/person.

In the Title 24 method (maximum of occupant- and area-based ventilation), it is not actually necessary to specify the OA-FLOW/AREA, as it is the smaller of the two quantities; UNLESS demand-controlled ventilation is used. In this case, the area-based value is used as a lower limit on outside air damper position to ensure that building-generated pollutants are diluted regardless of hourly occupancy.

Airside Control

The following keywords provide information on supply air temperature set point, control strategy, and limits, humidity limits, and equipment operating schedules.

MAX-SUPPLY-T

The maximum temperature of the air delivered to the zones in a system for sizing calculations (for many system types but not all). For certain terminal types, may also specify the maximum outlet temperature at the terminal.

For central airhandlers having heating and cooling coils in parallel (DDS, MZS, PMZS), specifies the design temperature leaving the airhandler and entering the supply duct. This temperature includes the effect of fan heat, but may be further modified by thermal gains in the air distribution system prior to entering the zonal terminals (see SYSTEM:HOT-DUCT-DT). Terminal sizing will be based on the temperature entering the terminal; thereby taking the distribution losses into account.

Note, that for dual-duct and multizone systems that are to maintain a constant heating air discharge temperature (see keyword HEAT-CONTROL), the control setpoint is determined by the value entered for HEAT-SET-T rather than MAX-SUPPLY-T . This setpoint is then used in the hourly calculations, after design sizing calculations are complete. (MAX-SUPPLY-T is used only during the sizing calculations; alternatively HEAT-SUP/RET-DT may be used).

For single-zone airhandlers that deliver either heated or cooled air according to the thermostat in a control zone (SZRH, SZCI, UVT, UHT, HP, FC, PSZ, PVVT, RESVVT), specifies the design heating temperature entering the supply duct when the control zone(s) call for heat. Like the DDS system types, this temperature may be modified by duct thermal losses prior to arriving at the terminal, and the terminal will be sized accordingly.

For single duct airhandlers that normally deliver cooled air to the zone terminals, this keyword has no meaning at the central level (the design supply T is the MIN-SUPPLY-T). Instead, it is an optional input that specifies the maximum temperature at the outlet of the terminal; downstream of any terminal heating coil and/or fan. When specified, a discharge air sensor is assumed to limit the maximum reheat to be no more than this value. This applies to both the design-sizing calculations as well as the hourly simulation. During sizing calculations, the reheat is calculated as the sum of the MIN-SUPPLY-T and REHEAT-DELTA-T, limited by the MAX-SUPPLY-T. For induction terminals in single duct air handlers, the optional MAX-SUPPLY-T is assumed to be at the outlet of the box. As such it does not necessarily represent the temperature leaving the heating coil. For example, in a parallel fan-powered terminal, the air leaving the heating coil mixes with the minimum cold duct airflow and then enters the zone. The MAX-SUPPLY-T applies to the mixed temperature entering the zone.

HEAT-SUP/RET-DT

Specifies the design differential between the zonal supply and return temperatures for zone airflow sizing calculations, when a zone is in the heating mode. When specified, this keyword takes precedence over the MAX-SUPPLY-T, REHEAT-DELTA-T, hourly zone temperature, or other combinations of values; the zonal heating airflow is a function of this differential and the extraction load.

This keyword has an identical keyword within the ZONE command. The default of the zonal keyword is the value specified at the SYSTEM level. At the zone level, this keyword overrides other temperatures, but does not override any user-defined airflows.

MIN-SUPPLY-T

For systems that can provide cooling, this is a required keyword that gives the minimum temperature of the air delivered to the zones for sizing calculations. This value is the temperature leaving the airhandler and entering the supply duct. This temperature includes the effect of fan heat, but may be further modified by thermal gains in the air distribution system prior to entering the zonal terminals (see SYSTEM:DUCT-DT and/or supply plenums). Terminal sizing will be based on the temperature entering the terminal; thereby taking the distribution losses into account.

Note, that for those systems that are to maintain a constant cooling air discharge temperature (see keyword COOL-CONTROL), the control set point is determined by the value entered for COOL-SET-T rather than MIN-SUPPLY-T. This setpoint is then used in the hourly calculations, after design sizing calculations are complete. (MIN-SUPPLY-T is used only during the sizing calculations; alternatively COOL-SUP/RET-DT may be used).

COOL-SUP/RET-DT

Specifies the design differential between the zonal supply and return temperatures for zone airflow sizing calculations when a zone is in the cooling mode. When specified, this keyword takes precedence over the MIN-SUPPLY-T, hourly zone temperature, or other combinations of values; the zonal heating airflow is a function of this differential and the extraction load.

This keyword has an identical keyword within the ZONE command. The default of the zonal keyword is the value specified at the SYSTEM level. At the zone level, this keyword overrides other temperatures, but does not override any user-defined airflows.

COOL-SET-T

The cooling air supply temperature setpoint when COOL-CONTROL = CONSTANT. Note that even though COOL-SET-T determines the cooling air supply temperature, the program uses MIN-SUPPLY-T during the design sizing calculations.

For all systems other than single-zone systems, this is the supply air temperature setpoint when COOL-CONTROL = CONSTANT; the default is MIN-SUPPLY-T - COOL-CTRL-RANGE/2.

For single-zone systems that are variable-volume (MIN-FLOW-RATIO specified and less than 1.0; PVVT, etc.), this keyword acts as the cooling setpoint when the control zone is calling for cooling. The default is the MIN-SUPPLY-T.

For single-zone systems that are constant volume (MIN-FLOW-RATIO not specified or equal to 1.0; PSZ, etc.), this keyword acts as a low-temperature cutout. The control zone resets the cooling temperature as required, and this keyword acts only as the lower limit. This can be important when the unit has an integrated economizer that might otherwise cause excessively cold supply temperatures on cool days. The default is the MIN-SUPPLY-T - 10F.

COOL-CTRL-RANGE

Throttling range of the heating and cooling coil controllers. It equals Ttop - Tbot, where Ttop and Tbot are the temperatures of the coil at the two extremes.

HEAT-CONTROL

Takes a code-word that specifies how the air temperature leaving the system heating coil is controlled. This control applies to dual-duct and single-duct systems provided the HEAT-SOURCE is specified and is not NONE. It does not apply to single-zone systems (PSZ, PVVT, SZRH, FC, etc.), as the supply temperature in those systems is determined by the control zone. Allowed values are:

CONSTANT	The supply air temperature is held nearly constant at HEAT-SET-T; it can change a few degrees due to fan heat and throttling range of the temperature controller.

COLDEST	Sets the heating coil (hot deck) temperature each hour to adequately heat the zone with the lowest temperature. The limits on the supply air temperature are then governed by HEAT-MAX-RESET-T, HEAT-MIN-RESET-T, coil capacities, and heating schedules.
	For dual-duct systems, the hot deck is reset to the demand of the coldest zone, taking into account the cold deck temperature and the minimum cold deck flow rate.
	For single-duct systems (VAVs, etc.), the hot deck is reset to the demand of the coldest zone, but the supply temperature will be limited by the temperature requested by the cold-deck controller. In addition, the supply temperature will never be set so warm that any zone is pushed out of the deadband into the cooling band.
RESET	Specifies use of HEAT-RESET-SCH for control of heating air supply temperature based on outdoor air temperature.
SCHEDULED	Specifies use of HEAT-SET-SCH for control of heating air supply temperature.

For single-duct systems having HEAT-CONTROL = COLDEST and COOL-CONTROL = WARMEST, the controller first looks to see if any ZONE has a cooling demand; if there is a ZONE cooling demand the AHU discharge temperature is reset to just satisfy the ZONE with the largest cooling demand. If no ZONE has a cooling demand, the controller looks to satisfy the ZONE with the greatest heating demand but without forcing any ZONE into creating a cooling demand. If neither a heating or cooling demand is found for any ZONE, mixed air is passed.

HEAT-SET-T
For dual-duct systems (MZS, DDS, PMZS), this is the supply air temperature setpoint when HEAT-CONTROL = CONSTANT; the default is MAX-SUPPLY-T + COOL-CTRL-RANGE/2.

For single-duct systems (VAVS, etc.), this is the supply air temperature setpoint when HEAT-CONTROL = CONSTANT. However, the output is limitied by the cooling controller. The default is the MIN-SUPPLY-T - COOL-CTRL-RANGE/2.

For single-zone systems that are variable-volume (MIN-FLOW-RATIO specified and less than 1.0; PVVT, etc.), this keyword acts as the heating setpoint when the control zone is calling for heating. The default is the MAX-SUPPLY-T.

For single-zone systems that are constant volume (MIN-FLOW-RATIO not specified or equal to 1.0; PSZ, etc.), this keyword acts as a high-temperature cutout. The control zone resets the heating temperature as required, and this keyword acts only as the upper limit. The default is the MAX-SUPPLY-T + 20F.

Cooling Equipment

COOLING-CAPACITY
Total capacity at rated conditions of either the chilled water cooling coil or the direct expansion cooling system, depending on which has been specified. This keyword overrides the calculated total (sensible + latent) cooling capacity of the system. It is especially useful for packaged units of integral sizes.

For a zonal system where the system creates a separate air handler for each zone (FC, HP, PTAC), this will be the cooling capacity for each zonal air handler. You may modify this value at the zonal level using the ZONE:COOLING-CAPACITY keyword.

For a chilled-water coil, the air entering the evaporator by default is assumed to be at 80°F entering drybulb and 67°F wetbulb; corresponding to the keywords RATED-EDB and RATED-EWB. The rated entering chilled-water temperature is assumed to be the CIRCULATION-LOOP:DESIGN-COOL-T. The rated airflow is the corresponding airflow entered by the user; if not specified then the rated flow is based on the FLOW/CAPACITY for central AHU and zonal coils. The rated chilled-water flow is specified as the CHW-COIL-DT.

For a packaged direct-expansion coil, the default rating conditions are those specified by ARI. The air entering the evaporator is assumed to be at 80°F entering drybulb and 67°F wetbulb; corresponding to the keywords RATED-EDB and RATED-EWB. The rated entering condenser temperature defaults to either 95°F for air-cooled equipment, or 85°F for water-cooled (RATED-ECT).

For a direct-expansion coil served by a condensing unit, the air entering the evaporator by default is assumed to be at 80°F entering drybulb and 67°F wetbulb; corresponding to the keywords RATED-EDB and RATED-EWB. The rated suction temperature at the coil is assumed to be the CONDENSING-UNIT:DESIGN-COIL-SST. The rated airflow is the corresponding airflow entered by the user; if not specified then the rated flow is based on the FLOW/CAPACITY for central AHU and zonal coils.

Note: When specifying COOLING-CAPACITY for packaged DX cooling units with drawthrough fans, SUPPLY-STATIC should be omitted and SUPPLY-KW/FLOW should be set equal to zero if the COOLING-CAPACITY includes cooling of the fan motor. Otherwise, the supply fan motor heat will be double counted. For better latent simulation the fan power should be specified (SUPPLY-STATIC or SUPPLY-KW/FLOW) and COOLING-CAPACITY adjusted to describe the unit without the fan. For DX systems, the program-calculated COOLING-CAPACITY is at ARI rated conditions and fan power and heat are not included. See keyword OUTSIDE-FAN-ELEC.

COOL-SIZING-RATI
Multiplier on the capacity of all cooling coils in the system, both within the air handler as well as within zone terminals. Allows you to modify the capacity of the cooling coil(s) without changing the system air flow rates. See SIZING-RATIO, above, which multiplies both coil capacities and air flow rates. If SIZING-RATIO is also specified, the net multiplier on the capacity of the cooling coil is [COOL-SIZING-RATI] x [SIZING-RATIO].

COOL-SH-CAP
Sensible heat removal capacity of the air cooling device at the rated conditions (the sensible part of COOLING-CAPACITY). This keyword should be related to the total cooling as most packaged units are 0.8 * (COOLING-CAPACITY). The sensible capacity is always less than or equal to the total capacity.

If input, then the program will use this value, together with the COOLING-CAPACITY, to calculate the SENS-HEAT-RATIO. Alternatively, the SENS-HEAT-RATIO may be entered directly (which is used internally to calculate the coil bypass factor). If neither the COOL-SH-CAP nor the SENS-HEAT-RATIO are specified, then the program will use the value of the COIL-BF keyword.

Note: It is recommended that COIL-BF be specified rather than either this keyword or the SENS-HEAT-RATIO. See the discussion under SENS-HEAT-RATIO.

RATED-EDB
specifies the entering drybulb temperature at which the COOLING-CAPACITY or COOLING-EIR is rated. The default is the ARI temperature.

RATED-EWB
specifies the entering wetbulb temperature at which the COOLING-CAPACITY or COOLING-EIR is rated. The default is the ARI temperature.

RATED-ECT
specifies the entering condenser temperature at which the COOLING-CAPACITY or COOLING-EIR is rated. The default is the ARI temperature, and varies according to whether the equipment is air-cooled or water-cooled.

COOL-SOURCE
For certain system types, takes a code-word that specifies the cooling source for the SYSTEM's main cooling coil. Not all system types that accept this keyword allow all cooling sources. Allowed values of COOL-SOURCE are:

NONE	No mechanical cooling is provided. Cooling may still be provided via natural ventilation or zonal sources.
CHILLED-WATER	The system uses a chilled-water coil. This option requires that you also specify the CHW-LOOP that supplies this system. Note: Not all systems allow this choice.
ELEC-DX	The system uses an electric direct-expansion compressor. Both air-cooled and water-cooled CONDENSER-TYPEs are supported. When using this option, you specify the DX performance in a manner identical to packaged-VAV or packaged single-zone systems; using the COOLING-EIR, etc. Note: Not all systems allow this choice.

COOL-CAP-FT
For direct expansion coils only, takes the U-name of a bi-linear or bi-quadratic curve that gives the capacity of the cooling coil or cooling system as a function of entering wet-bulb temperature and outside dry-bulb temperature. If the curve is for a Water Loop Heat Pump system (HP), the curve gives the coil cooling capacity as a function of entering wet-bulb temperature and entering water temperature. The value of the curve is usually normalized to 1.0 at rated conditions, but this is not mandatory; the program will normalize the curve internally.

Note that, for chilled-water coils, this curve is no longer used. Instead, the program uses an enthalpy-based NTU/effectiveness heat exchanger model which yields better results, especially for off-rated airflows and/or chilled-water temperature reset.

COOL-SH-FT
No longer used. The hourly sensible heat removal capacity is now determined by the entering coil conditions, the hourly total coil capacity, and the coil bypass factor, where the bypass factor is adjusted for airflow.

COIL-BF
This is the cooling coil full load rated bypass factor; specified at the rating point FLOW/CAPACITY. The coil bypass factor and flow/capacity are both defined at sea level; any adjustment to airflow for altitude will then result in a modification to the coil bypass factor. In lieu of the FLOW/CAPACITY, the COOLING-CAPACITY and SUPPLY-FLOW may be specified instead.

This value is used to characterize the performance of a cooling coil. Using the bypass model, the exit air stream from a coil is characterized as being composed of two components: one component leaves the coil at the coil surface temperature and at, or below, the corresponding saturation humidity ratio above or below this saturation value); the other component leaves at the same temperature and humidity ratio as the entering air stream (thus the bypass name). The fraction of the total air flow in the bypassed component is the bypass factor.

SENS-HEAT-RATIO

An alternative to specifying the COIL-BF. Defines the ratio of sensible to total cooling capacity. The program will use this value, together with the air inlet conditions, airflow, and total capacity to calculate the coil bypass factor. Normally, you should also specify the FLOW/CAPACITY, RATED-EDB and RATED-EWB. In lieu of the FLOW/CAPACITY, the COOLING-CAPACITY and SUPPLY-FLOW may be specified instead. While not mandatory, completely specifying the coil will ensure that a reasonable coil bypass factor is calculated. Otherwise, unexpected combinations of default air inlet conditions, airflow, and required capacity may result in an unreasonable coil bypass factor.

Using this keyword in place of the COIL-BF is potentially dangerous, and it is recommended that the COIL-BF be specified instead. While manufacturers of packaged DX equipment publish total and sensible capacities for a wide range of airflows and entering air conditions, typically only one or a few points are measured in the laboratory, such as the ARI rating point; the rest of the table is calculated based on interpolated or extrapolated points. A survey of data from several major manufacturers revealed that, at the extremes of airflows and entering air conditions, the published sensible heat ratios often resulted in coil bypass factors that were either:

> Negative - the coil was operating in the fog region,

> Non-existent - the coil bypass could not be calculated because the line determined by the entering and leaving conditions did not intersect the saturation curve (the slope of the sensible heat ratio was too steep).

For this reason, it is recommended that the COIL-BF be calculated based on a single calibrated point, and the COIL-BF-FT curve be allowed to default to null.

COIL-BF-FT

Takes the U-name of a bi-linear or bi-quadratic curve that gives the coil bypass factor as a function of the entering wet-bulb temperature and entering dry-bulb temperature. The curve should be normalized so that at rated conditions its value is 1.0. (Normally, this curve is not specified, and the default is null; so that the bypass factor is independent of entering air conditions)

COIL-BF-FFLOW

No longer used. The program now calculates this dependence using an exponential function that forces this value to be 1.0 at the rated flow, and 0.0 at a flow of zero.

COIL-BF-FPLR

No longer used. For cycling coils, the program now calculates this value as a function of the time the coil is cycled.

CHW-CAP-FEWBEWT

No longer used. In lieu of performance curves, chilled-water coils use an enthalpy-based NTU/effectiveness coil model.

CHW-CAP-FFLOW

No longer used. In lieu of performance curves, chilled-water coils use an enthalpy-based NTU/effectiveness coil model.

COOLING-EIR

The Electric Input Ratio (EIR), or 1/(Coefficient of Performance), or 3.413/EER, for the cooling unit at rated conditions. The program defines EIR to be the ratio of the electric energy input to the rated capacity, when both the energy input and rated capacity are expressed in the same units. This EIR is at rated conditions, i.e., without correction for different temperature or part load. The rated conditions default to ARI, but may be specified using RATED-EDB, RATED-EWB and RATED-ECT.

ECONO-SCHEDULE

accepts the U-name of a schedule of type ON/OFF, ON/OFF/TEMP or TEMPERATURE that enables, but does not control economizer operation. Normally, the economizer may operate whenever the fan is running, depending on the type of OA-CONTROL.

A value of 0 in the ECONO-SCHEDULE forces the economizer to its minimum position, regardless of other controls. A value of 1 allows the economizer to operate according to the specified OA-CONTROL sequence. If the schedule is of the type which allows a temperature to be input, the temperature is the outdoor drybulb temperature above which the economizer operates according to the specified OA-CONTROL sequence.

Note that, by default, the economizer is allowed to operate during design sizing calculations; potentially reducing the peak cooling load used for sizing. To disable the economizer during design sizing, define an ECONO-SCHEDULE with a DAY-SCHEDULE value of 1.0 for Mondays thru Holidays, and a DAY-SCHEDULE value of 0.0 for the heating design-day (HDD) and/or cooling design-day (CDD).

Heating Equipment

HEATING-CAPACITY

Heating capacity at rated conditions of the system, entered as a negative value. If not input, it will be calculated by the program.

For a zonal system where the system creates a separate air handler for each zone (UVT, UHT, FC, HP, PTAC, FP), this will be the heating-capacity for each zonal air handler. You may modify this value at the zonal level using the ZONE:HEATING-CAPACITY keyword.

For a hot-water coil, the rated condition of the air entering the coil is assumed to be at 70°F entering drybulb; corresponding to the keyword HT-RATED-EDB. The rated entering hot-water temperature is assumed to be the CIRCULATION-LOOP:DESIGN-HEAT-T. The rated flow is the corresponding airflow entered by the user; if not specified then the default flow will be used.

For a heat-pump coil, the rated condition of the air entering the coil is assumed to be at 70°F entering drybulb (HT-RATED-EDB). The rated entering condenser temperature for 47°F if air-cooled, or 70°F if water-cooled (HT-RATED-ECT).

The heating capacity of a heat pump is related to its cooling capacity via the HEAT/COOL-CAP, where HEAT/COOL-CAP is defined at the rated conditions (RATED-EDB, RATED-EWB, RATED-ECT for cooling; HT-RATED-EDB, HT-RATED-ECT for heating).

If an air-cooled heat pump is sized by the program, its compressor capacity is normally determined by the cooling requirement. The heating requirement is not directly used as a criteria, as heat pumps are not normally sized to the peak heating load. However, up to 50% of the heating requirement is credited toward the compressor size; this is useful for heating-dominated climates (the supplemental heater is assumed to make up the additional heat required):

    Compressor capacity = max [rated cooling capacity,
                                            rated heating capacity / HEAT/COOL-CAP * 0.5]

A water-cooled heat pump does not have supplemental heat. For these systems, the default capacity is the larger or the cooling or heating requirement:

Compressor capacity = max [rated cooling capacity,
                                                  rated heating capacity / HEAT/COOL-CAP]

If either the HEATING-CAPACITY or the COOLING-CAPACITY of a heat pump is specified by the user, then the complementary quantity will be calculated using this ratio. If both HEATING-CAPACITY and COOLING-CAPACITY are specified, the program will use both, but will issue a warning if the values are not reasonable relative to each other.

For coil types other than heat pump that are sized by the program, the criteria used for sizing the coil depends on the appropriate sizing method keyword:

> HT-SIZING-METHOD for central heating coils
> PHT-SIZING-METHO for preheat coils
> RHT-SIZING-METHOD for reheat coils

While the specific choices vary by coil application, the choices fall into the following categories (see the coil-specific keyword for more information):

- <u>Size by default</u> – The heating coil is sized based on the peak design-day load. This method will often result in unrealistically small loads for cooling-dominated systems. For example, in a packaged rooftop system, the size of the unit is typically determined by the cooling load, and there may be only one or two sizing selections available for the heating coil.

- <u>Size based on supply temperature</u> – The heating coil is sized based on a specified supply temperature, the coil inlet temperature determined by the design-day simulation, and an air flow that is some fixed fraction of the cooling-based supply airflow.

- <u>Size based on coil temperature rise</u> – The heating coil is sized based on a specified coil temperature rise, and an airflow that is some fixed fraction of the cooling-based supply airflow.

The program does not round up or round down the calculated capacity to correspond to the integral sizes that are available for packaged units. If desired, you can to do this manually after the calculated value is known.

HT-RATED-EDB
specifies the entering drybulb temperature at which the HEATING-CAPACITY or HEATING-EIR is rated. The default is the ARI temperature.

HT-RATED-ECT
specifies the entering condenser temperature at which the HEATING-CAPACITY or HEATING-EIR is rated. The default is the ARI temperature.

HRATED-FLOW
specifies the airflow at which the HEATING-CAPACITY or HEATING-EIR is rated.

HT-SIZING-METHOD
Defines the method used in design sizing to calculate the central heating coil capacity. Allowed values are:

DEFAULT   Allow the program to size the coil based on the load on the design day. This may result in unrealistically low supply air temperatures if the design heating load is low relative to cooling load.

MAX-SUPPLY-T	Coil is sized to provide the specified MAX-SUPPLY-T at the design heating air flow. This is the default sizing method in the program.
HT-COIL-AIR-DT	Allows the user to specify the temperature rise across the heating coil at the design heating air flow, using the keyword HT-COIL-AIR-DT.

HEAT-COIL-AIR-DT
The temperature rise across the central heating coil that is used for design sizing calculations when HT-SIZING-METHOD is set to HT-COIL-AIR-DT.

PHT-SIZING-METHOD
Defines the method used in design sizing to calculate the preheat coil capacity. Allowed values are:

DEFAULT	Allow the program to size the coil based on the load on the design day. This may result in unrealistically low supply air temperatures if the heating load is low relative to cooling load.
PREHEAT-T	Coil is sized to provide the specified PREHEAT-T at the design heating air flow. This is the default sizing method in the program.
PHT-COIL-AIR-DT	Allows the user to specify the temperature rise across the heating coil at the design heating air flow, using the keyword PHT-COIL-AIR-DT.

PHT-COIL-AIR-DT
The temperature rise across the preheat coil that is used for design sizing calculations when PHT-SIZING-METHOD is set to PHT-COIL-AIR-DT.

RHT-SIZING-METHOD
Defines the method used in design sizing to calculate the reheat coil capacity. Allowed values are:

DEFAULT	Coil is sized based on the load on the design day. This may result in unrealistically low supply air temperatures if heating load is low relative to cooling load.
REHEAT-DELTA-T	Coil is sized to provide the specified REHEAT-DELTA-T at the design heating air flow. This is the default sizing method in the program for systems that also have a central heating coil.
MAX-SUPPLY-T	Coil is sized to provide the specified MAX-SUPPLY-T at the design heating air flow. This is the default sizing method in the program for systems that do not have a central heating coil.

HEAT/COOL-CAP
For a heat pump, is the ratio of the heating capacity to the cooling capacity, where the heating capacity is at the rated heating conditions and the cooling capacity is at the rated cooling conditions. In the heating mode, the rated conditions are HT-RATED-EDB and HT-RATED-ECT. In the cooling mode, the rated conditions are RATED-EDB, RATED-EWB and RATED-ECT.

If a heat pump is sized by the program, its compressor capacity is determined by the larger of the heating and cooling requirements as follows:

Compressor capacity = max [rated cooling capacity,
                                     rated heating capacity / HEAT/COOL-CAP]

If either the HEATING-CAPACITY or the COOLING-CAPACITY of a heat pump is specified by the user, then the complementary quantity will be calculated using this ratio. If both HEATING-CAPACITY and COOLING-CAPACITY are specified, the program will use both, but will issue a warning if the values are not reasonable relative to each other.

HW-CAP-FDT
No longer used. In lieu of performance curves, hot-water coils use an NTU/effectiveness coil model.

HW-CAP-FFLOW
No longer used. In lieu of performance curves, hot-water coils use an NTU/effectiveness coil model.

PREHEAT-CAPACITY
Total capacity of the preheat coil at the rated conditions. The input value is negative. If this value is not specified, but PREHEAT-T is specified, then the program will calculate the preheat capacity as a function of the outdoor air quantity, the design outdoor dry-bulb temperature, and PREHEAT-T.

PREHEAT-FLOW
The airflow corresponding to the PREHEAT-CAPACITY. If not specified, the default is the design preheat airflow. If SITE-PARAMETERS:SPECIFY-AIRFLOWS = SEA-LEVEL, then this flow is assumed to be at sea-level, and will be corrected to the equivalent airflow at the actual building altitude.

PHT-RATED-EDB
The entering drybulb temperature corresponding to the PREHEAT-CAPACITY.

CIRCULATION-LOOP
SIZING-OPTION
Accepts a code-word specifying the method to use in sizing the loop.

COINCIDENT	the default for all loop types except CW, specifies that the loop (and attached boilers, chillers, etc.) is to be sized based on the coincident (simultaneous) load of all coils, equipment, and process loads.
	When using this option, you should always review report PS-D to verify whether significant equipment overloads exist. This can happen if the design-sizings do not fully capture the loads the occur during the weather year.
NON-COINCIDENT	the default for CW loops, specifies that the loop is to be sized on the non-coincident load of all coils, equipment, and process loads. This results in the largest-sized equipment.
PRIMARY	Specifies that the design loop load is to be based on the sum of the primary equipment capacities that are attached to this loop. In order for this code-word to be valid, you must enter the capacity of the boilers, chillers, etc. that supply this loop. Otherwise, the program will give a warning message that this keyword will be ignored, and will size the loop based on the coincident loads instead.
SECONDARY	*this is an older definition; it has the same meaning as NON-COINCIDENT.*

SIZING-WINDOW
accepts a code-word specifying the window of time during the design-sizings in which equipment is to be sized:

ACTIVE-PEAK	the default, specifies that a given equipment unit is to be sized based on the peak load that occurs *during the time in which the equipment (boiler or chiller) is active.* This peak may or may not coincide with the circulation-loop's maximum peak, depending on how the equipment is controlled.
MAXIMUM-PEAK	specifies that a given equipment unit (boiler or chiller) is to be sized on the circulation-loop's maximum design-sizing peak, regardless of whether the equipment is actually operating on peak.

During the design-sizings, an equipment unit is sized based on the load actually allocated to the equipment unit. However, if the equipment does run during the design days, then the equipment will not be sized. Or, if the equipment runs during the design days, but is not scheduled to run during the hour of peak consumption, then the equipment might be undersized.. Normally, ACTIVE-PEAK is suitable. The following two examples illustrate when MAXIMUM-PEAK should be used instead:

1. Multiple equipment units, significantly oversized – Consider a plant with 3 chillers, each having a specified CAPACITY-RATIO = 0.6 When each is sized to 0.6 of the peak load, the combined capacity of any two of the chillers will be 120% of the load, and the capacity of all three chillers will be 180% of the load. If an EQUIP-CTRL sequence is not specified that forces all three units to run simultaneously, then by default the program will select only two units to run. As a result, the third chiller will not be sized.

2. Time-of-use EQUIP-CTRL sequences – Consider a plant having two chillers, one of which is a gas-fired unit intended to run during the peak afternoon summer period, and an electric chiller intended to run during other hours. The user has specified a LOAD-MANAGEMENT sequence that switches EQUIP-CTRL sequences based on a schedule. If the schedule fails to run both units during the design-sizing simulation, then the unit that did not run will not be sized.

LOOP-SIZE-RATIO
For either coincident or non-coincident sizing, applies a factor of safety to the sizing calculation. The calculated load and flow are multiplied by this factor prior to sizing water-side equipment.

Note that sizing factors can multiply on each other. For example, if you specify a LOOP-SIZE-RATIO = 1.1 and a BOILER:CAPACITY-RATIO = 1.2, the actual size of the boiler relative to the coil load will be 1.1 * 1.2 = 1.32. If in addition the SYSTEM:SIZING-RATIO = 1.2, then the boiler capacity is 1.32 * 1.2 = 1.58 times the peak load.

DESIGN-HEAT-T
For loops that can heat, specifies the design hot-water supply temperature. This value may be used in the design calculations for various components, such as boilers and chillers. If you do not specify this value, the temperature used in the design-sizing calculations will be the temperature as specified by the HEAT-SETPT-T, HEAT-SETPT-SCH, or other temperature control strategy.

For a WLHP loop this is the design temperature used for components that draw heat from the loop, such as a water-to-air heat pump or a CHILLER of TYPE = HEAT-PUMP. As such, this value should represent the winter condition.

DESIGN-COOL-T
For loops that can cool, specifies the design chilled-water supply temperature. This value may be used in the design calculations for various components, such as chillers. If you do not specify this value, the temperature used in the design-sizing calculations will be the temperature as specified by the COOL-SETPT-T, COOL-SETPT-SCH, or other temperature control strategy.

For a WLHP loop this is the design temperature used for components that reject heat to the loop, such as a water-to-air heat pump or a CHILLER of TYPE = HEAT-PUMP. As such, this value should represent the summer condition.

SUPPLY-ENVIR-TD
When calculating the loop's UA loss factor for thermal losses on the supply leg, specifies the mean temperature differential between the pipe and the pipe's environment. The UA factor is calculated as a function of this value, the fluid temperature, fluid flow, and the fluid temperature change:

This keyword replaces HEATING-ENVIR-T, COOLING-ENVIR-T, and LOSSES-BASED-ON

RETURN-ENVIR-TD
When calculating the loop's UA loss factor for thermal losses on the return leg, specifies the mean temperature differential between the pipe and the pipe's environment. The UA factor is calculated as a function of this value, the fluid temperature, fluid flow, and the fluid temperature change:

This keyword replaces HEATING-ENVIR-T, COOLING-ENVIR-T, and LOSSES-BASED-ON

PROCESS-HEAD
Specifies the head (pressure) loss of the process load, corresponding to the PROCESS-FLOW or PROCESS-LOAD-DT.

BOILER
The program distinguishes between the conditions at which a boiler's performance is rated, versus the conditions to which a component is to be designed to operate:

- Rated conditions - If you specify a CAPACITY, START-UP-TIME, ELEC-INPUT-RATIO, HEAT-INPUT-RATIO, HW-HEAD, etc., those values may correspond to a certain set of hot-water and ambient conditions (temperatures and flow). These are the *rated conditions*.

  For example, for a gas-fired boiler, the boiler's performance is defined using the keywords CAPACITY, ELEC-INPUT-RATIO, HEAT-INPUT-RATIO, START-UP-TIME, and HW-HEAD. The rated conditions corresponding to these criteria are RATED-HW-T, RATED-AMBIENT-T, and RATED-HW-DT.

  Note that, by default, none of the boiler types have performance curves that modify capacity or energy consumption as a function of temperature. Therefore, the RATED-HW-T and RATED-AMBIENT-T have no effect unless curves are also defined.

- Design conditions – If you allow the program to auto-size a boiler, the program will size the boiler to match the design conditions (both hot-water loop and ambient temperature) encountered during the design-day run-periods. These design conditions are usually not the same as the rated conditions. Since the default ELEC-INPUT-RATIO or HEAT-INPUT-RATIO is specified at the rated conditions, the program converts power ratio from the rated conditions to the design conditions in order to properly calculate the default power consumption.

  The default design conditions may not match your intended sizing criteria. For example, based on the DESIGN-HEAT-T of the hot-water loop, the program may size the boiler to a hot-water supply temperature of 160°F at 30°F ambient temperature. If instead you want the boiler sized to 180°F and 15°F respectively, you may specify these criteria using DESIGN-HW-T and DESIGN-AMBIENT-T.

Note that, unless performance curves for capacity and/or energy consumption are defined, the design keywords have no effect.

The following keywords describe the rating conditions of a boiler:

RATED-HW-T
The leaving hot-water temperature at the rated conditions. The CAPACITY, ELEC-INPUT-RATIO, and/or HEAT-INPUT-RATIO are all specified at this condition.

RATED-AMBIENT-T
The ambient temperature at the rated conditions. The CAPACITY, ELEC-INPUT-RATIO, and/or HEAT-INPUT-RATIO are all specified at this condition.

RATED-HWR-T
For the HW-CONDENSING boiler, specifies the return water temperature at which both the CAPACITY and HEAT-INPUT-RATIO are defined. The default is 80°F (26.7°C).

RATED-HW-DT
HW-DT (old keyword)
Specifies the temperature rise through the boiler at the rated conditions. The HW-HEAD is defined relative to this value. If you do not specify the dT, then the head is not adjusted for the actual flow encountered during design (but is still adjusted hourly during the simulation).

The next set of keywords describe the design conditions of a boiler:

DESIGN-HW-T
The leaving hot-water temperature at the design conditions. If not specified, the program will size the boiler to the temperature required by the hot-water loop.

DESIGN-HWR-T
For the HW-CONDENSING boiler, specifies the return hot-water temperature at the design conditions. If not specified, the program will size the boiler to the actual return temperature of the hot-water loop.

DESIGN-AMBIENT-T
The ambient temperature at the design conditions. The default is the design-day ambient temperature at the peak load. The ambient temperature is either indoors or outdoors depending on the boiler location.

The following keywords summarize how boiler performance is defined. Please refer to the Dictionary for the complete list of keywords.

CAPACITY
The nominal (or rated) heating capacity of the boiler. If the capacity is temperature dependent, (curve CAP-FT is specified), the capacity corresponds to the RATED-HW-T and RATED-AMBIENT-T.

For the HW-CONDENSING boiler, the capacity corresponds to the rated return temperature, RATED-HWR-T. The default is 80°F (26.7°C).

If you do not specify CAPACITY,

> If CAPACITY-RATIO is specified, the capacity defaults to the maximum design-day heating loop capacity, multiplied by the CAPACITY-RATIO.

> If no CAPACITY-RATIO is specified, the capacity defaults to the maximum design-day heating loop capacity, divided by the number of boilers attached to the loop, and multiplied by the loop's SIZING-RATIO.

CAPACITY-RATIO
The fraction of the design heating loop capacity that the boiler will be sized to meet. Used only if CAPACITY is not specified. If you are defining two boilers of identical size that exactly meet the design loop load, set each boiler's CAPACITY-RATIO to 0.5. To include a 20% safety factor, set each boiler's CAPACITY-RATIO to 0.6. If no CAPACITY-RATIO is specified, the capacity defaults to the maximum design-day heating loop capacity, divided by the number of boilers attached to the loop, and multiplied by the loop's SIZING-RATIO. (The SYSTEM:SIZING-RATIO and SYSTEM:HEAT-SIZING-RATI also act to increase design load.)

HEAT-INPUT-RATIO
The ratio of fuel heat input to boiler heating capacity at full load (i.e., at the rated conditions). Used only for fuel-consuming boilers. Note that this is a dimensionless ratio, so you must convert fuel consumption and heating capacity to the same units before dividing. If the energy consumption is temperature dependent, (curve HIR-FT is specified), the heat input ratio corresponds to the RATED-HW-T and RATED-AMBIENT-T.

ELEC-INPUT-RATIO
The ratio of electric input power to nominal boiler capacity. The EIR is dimensionless, so the same units for input and capacity should be used when calculating it. The default is 1.0 for electric boilers (ELEC-HW-BOIL and ELEC-STM-BOIL. If the energy consumption is temperature dependent, (curve EIR-FT is specified), the electric input ratio corresponds to the RATED-HW-T and RATED-AMBIENT-T.

EIR-FT
Takes the U-name of a curve that modifies the electric consumption as a function of the supply temperature and the environmental temperature. There is no default; if not specified then the ELEC-INPUT-RATIO is assumed constant for all temperature conditions. The supply temperature is the greater of the loop supply setpoint, or the boiler's internal AQUASTAT-SETPT-T. The LOCATION keyword determines whether the environmental temperature is the outdoor air temperature or a zone temperature.

HW-PUMP
Takes the U-name of the PUMP that serves the boiler's hot water loop. If you do not assign this pump, the boiler head requirement is passed to the attached primary loop. Additionally, this boiler pump may be a equipment-recirculation pump, or, if the hot water loop does not have its own pump, this boiler pump will also power the primary loop. In this case, the head of this pump will be the sum of the maximum coil head, the loop distribution head (including static head), and the boiler head. The hourly flow of the pump (and boiler) will be determined based on the loop flow and the number of other boilers running.

If you do not specify the capacity of the pump, the pump will be sized on the basis of the HW-MAX-FLOW, defined as the ratio of the maximum allowable flow to the rated flow.

The HW-PUMP is assumed to be external to the boiler, so its pump heat is included in the net loop load in the reports, and its heat decreases the heating load of the attached boiler.

HW-DT

The design temperature change of the hot water through the boiler. The default is the LOOP-DESIGN-DT of the attached loop. The program uses this keyword to determine the boiler's design flow, which in turn is used to size the equipment-recirculation pump, if any, on the boiler, and calculate the hourly pressure drop. If no equipment-recirculation pump exists, the flow through the boiler is based on the LOOP-DESIGN-DT.

HW-HEAD

The head loss through the boiler at design flow. For design purposes of pumps, the head at the rated flow is adjusted to the head that occurs at the maximum allowable flow, HW-MAX-FLOW. Hourly, the head loss varies with the actual flow.

If you specify the RATED-HW-DT, then the head corresponds to this temperature rise. The design head on the loop, and pumps is then calculated as a function of the rated head; modified as a function of the actual temperature rise vs. the rated rise. If the rated rise is not specified, then the design head is simply the rated head.

DW-HEATER

The program distinguishes between the conditions at which a water heater's performance is rated, versus the conditions to which a component is to be designed to operate:

- Rated conditions - If you specify a CAPACITY, ELEC-INPUT-RATIO, HEAT-INPUT-RATIO, etc., those values may correspond to a certain set of hot-water and ambient conditions (temperatures and flow). These are the *rated conditions*.

  For example, for a heat-pump heater, the heater's performance is defined using the keywords CAPACITY and ELEC-INPUT-RATIO. The rated conditions corresponding to these criteria are RATED-DHW-T and RATED-AMBIENT-T.

  Note that, by default, only the heat-pump heater has performance curves that modify capacity and energy consumption as a function of temperature. Therefore, the RATED-HW-T and RATED-AMBIENT-T have no effect for gas or electric heaters unless curves are also defined.

- Design conditions – If you allow the program to auto-size a water heater, the program will size the heater to match the design conditions (both dhw-water loop and ambient temperature) encountered during the design-day run-periods. These design conditions are usually not the same as the rated conditions. Since the default ELEC-INPUT-RATIO or HEAT-INPUT-RATIO is specified at the rated conditions, the program converts power ratio from the rated conditions to the design conditions in order to properly calculate the default power consumption.

  The default design conditions may not match your intended sizing criteria. For example, based on the DESIGN-HEAT-T of the dhw loop, the program may size the heater to a supply temperature of 120°F at 30°F ambient temperature. If instead you want the heater sized to 130°F and 45°F respectively, you may specify these criteria using DESIGN-DHW-T and DESIGN-AMBIENT-T.

The following keywords describe the rating conditions of a heater:

RATED-DHW-T

The leaving hot-water temperature at the rated conditions. The CAPACITY, ELEC-INPUT-RATIO, and/or HEAT-INPUT-RATIO are all specified at this condition.

RATED-AMBIENT-T

The ambient temperature at the rated conditions. The CAPACITY, ELEC-INPUT-RATIO, and/or HEAT-INPUT-RATIO are all specified at this condition.

The next set of keywords describe the design conditions of a water heater:

DESIGN-DHW-T

The leaving hot-water temperature at the design conditions. If not specified, the program will size the heater to the temperature required by the dhw loop.

DESIGN-AMBIENT-T

The ambient temperature at the design conditions. The default is the design-day ambient temperature at the peak load. The ambient temperature is either indoors or outdoors depending on the heater location.

DESIGN-HP-MIN-T

For a heat-pump water heater, is the minimum allowable temperature to be used for sizing the unit. For example, if the peak design-day load occurs at an ambient temperature of 10°F, but you do not want the heat-pump to be sized to such a low temperature, you may specify 45°F for this keyword. The heat pump will then be sized to the peak load, but at an ambient temperature of 45°F instead of 10°F.

CHILLER

The program distinguishes between the conditions at which a chiller's performance is rated, versus the conditions to which a component is to be designed to operate:

- Rated conditions - If you specify a CAPACITY, START-UP-TIME, ELEC-INPUT-RATIO, HEAT-INPUT-RATIO, CHW-HEAD, etc., those values correspond to a certain set of evaporator and condenser conditions. These are the _rated conditions_. By default, the rated conditions correspond to the ARI standard conditions, although this is not a requirement. You may specify the chiller performance at a non-ARI set of conditions as long as you completely specify the non-ARI conditions. Note that ALL of the chiller performance criteria must be defined at a given set of conditions. For example, if the CAPACITY is specified at a leaving chilled-water temperature of 42°F and entering condenser temperature of 80°F, then the ELEC-INPUT-RATIO must also be defined for those same conditions.

  For example, for a water-cooled reciprocating chiller, the chiller's performance is defined using the keywords CAPACITY, ELEC-INPUT-RATIO, START-UP-TIME, CHW-HEAD, and CW-HEAD. The rated conditions corresponding to these criteria are RATED-CHW-T, RATED-CHW-FLOW, RATED-COND-T and RATED-CW-FLOW.

- Design conditions – If you allow the program to auto-size a chiller, the program will size the chiller to match the design conditions (both evaporator and condenser loops) encountered during the design-sizing run-periods. These design conditions are usually not the same as the rated conditions. Since the default ELEC-INPUT-RATIO or HEAT-INPUT-RATIO is specified at the rated conditions, the program converts power ratio from the rated conditions to the design conditions in order to properly calculate the default power consumption.

  The default design conditions may not match your intended sizing criteria. For example, based on the DESIGN-COOL-T of the chilled-water and condenser loops, the program may size the chiller to a chilled-water supply temperature of 44°F and an entering condenser temperature of 85°F. If instead you want the chiller sized to 42°F and 80°F respectively, you may specify these criteria using DESIGN-CHW-T and DESIGN-COND-T. If the intended condenser flow is other than the flow at the rating conditions, you may specify it using DESIGN-CW-FLOW or DESIGN-CW-DT.

Most chiller types can be specified at either the ARI standard rating conditions, or at a different set of rated conditions (such as the actual design conditions). However, for centrifugal chillers, it may not make sense to specify performance at the ARI rated conditions, as the chiller *may not be able to actually operate at those conditions*.

For example, consider a water-cooled centrifugal chiller serving a building in a relatively cool, dry climate. The engineer specifies the chiller capacity and efficiency at 46°F leaving chilled water and 76°F entering condenser water. To achieve the specified efficiency at minimum cost, assume the chiller manufacturer configures the the impeller and heat-exchangers to exactly meet the design conditions. If this chiller is then operated at the more extreme ARI conditions of 44°F/85°F, the compressor may not be able to overcome the pressure differential between the evaporator and condenser, and the chiller will surge if it tries to deliver water at 44°F. To operate successfully at 85°F entering condenser water, it will have to deliver water warmer than 44°F.

For this reason, you should always verify whether the default rated conditions are appropriate for your centrifugal chillers.

The following keywords describe the rating conditions of a chiller, either ARI or other:

RATED-CHW-T
The leaving chilled-water temperature at the rated conditions, either ARI or other. The CAPACITY, ELEC-INPUT-RATIO, and/or HEAT-INPUT-RATIO are all specified at this condition.

RATED-CHW-FLOW
The chilled water flow per unit capacity at the rated conditions, (GPM/ton or L/S-KW). The CHW-HEAD is specified at this value, and will be modified if the actual flow is different from the rated flow.

For centrifugal chillers, the manufacturer usually adjusts the number of passes through the evaporator in accordance with the evaporator's design temperature drop. DOE-2 recognizes this practice, and adjusts the default CHW-HEAD and RATED-CHW-FLOW as a function of the CIRCULATION-LOOP:LOOP-DESIGN-DT and if the chiller is in series with another chiller.

RATED-CHW-DT
CHW-DT (old keyword)
is an alternative to RATED-CHW-FLOW, and specifies the temperature drop through the chiller evaporator at the rated conditions. This keyword overrides the RATED-CHW-FLOW.

RATED-COND-T
The condenser temperature at the rated conditions, either ARI or other. The meaning of this keyword and the default value vary according to the condenser type:

- <u>Water-cooled</u> – The entering condenser water temperature. The default is 85°F, when the RATED-CW-FLOW is 3.0 gpm/ton.

- <u>Air-cooled</u> – The entering air temperature. The default is 95°F.

- <u>Remote condenser</u> – The saturated condensing temperature. The default is 125°F for both air-cooled and evaporatively-cooled condensers.

RATED-CW-FLOW
For a water-cooled condenser, specifies the condenser flow at the rated conditions, either ARI or other. For electric chillers, the default is 3.0 gpm/ton. The default varies for other chiller types. While the RATED-CW-FLOW corresponds to the condtions at which the CAPACITY, ELEC-INPUT-RATIO, etc. are specified, the actual condenser flow may be different, and is specified by DESIGN-CW-FLOW.

Why is this keyword relevant? Chiller manufacturers normally report performance as a function of the *entering* condenser water temperature and a rated flow, and the DOE-2 performance curves conform to this convention. However, the *leaving* condenser water temperature is actually a more important determinant of chiller performance, and must be taken into account when simulating a chiller with a condenser flow other than the rated flow. The program uses this keyword to bias the entering condenser temperature for off-rated and/or variable condenser flows.

For example, assume a chiller operating at a 3 gpm/ton condenser flow has a 9°F rise through the condenser at rated conditions. In this case, an 85°F entering condenser temperature corresponds to 94°F leaving temperature. If the condenser flow is reduced to 2 gpm/ton, then the rise will be approximately 15°F and the leaving temperature will be 100°F. To account for this increase in leaving temperature, the program will bias the entering temperature by 6°F, so that the value used in the curves for entering condenser temperature is 91°F instead of 85°F. (This example oversimplifies the problem; the program iterates to find the balance point between the biased entering condenser temperature, and the impact of that temperature on capacity, power consumption, rejected heat, and leaving temperature.)

RATED-CW-DT
is an alternative to RATED-CW-FLOW, and specifies the temperature rise through the condenser at the rated conditions. This keyword overrides the RATED-CW-FLOW.

RATED-PLR
DESIGN-PLR (old keyword)
For centrifugal chillers only, specifies the ratio of the design capacity to the maximum capacity. The maximum capacity of a centrifugal chiller is often greater than the design capacity; either because of the components used to build up the chiller, or in order to meet the efficiency requirements at the specified conditions.

For example, consider a chiller specified to deliver 500 tons at 44°F chilled water, 80°F entering condenser water at 3 gpm/ton, and 0.6 kW/ton power consumption. The chiller manufacturer might determine that the least expensive chiller that meets the specifications is actually one having a maximum capacity of 550 tons and a power consumption of 0.64 kW/ton at full load. However, when unload to 500 tons, the efficiency of the chiller improves, and the part load power consumption is 0.6 kW/ton; thereby meeting the engineer's specifications. (Centrifugal chillers are most efficient when running at part load.)

To specify the above chiller in DOE-2, set

```
        CAPACITY          = 6.        $ 500 tons *12000 Btu/ton / 1000000
        ELEC-INPUT-RATIO  = 0.171     $ 0.6 kW/ton * 3413 Btu/kW / 12000 Btu/ton
        RATED-PLR         = 0.91      $ 500 design tons / 550 maximum tons
        RATED-CHW-T       = 44.
        RATED-COND-T      = 80.
        RATED-CW-FLOW     = 3.
```

The capacity and power performance curves are always normalized relative to the maximum capacity (PLR = 1.0), not the design capacity (PLR < 1.). The RATED-PLR keyword identifies the design point relative to the maximum operating point on the performance curves.

Example Input:

```
    "Electric Water-Cooled Centrifugal" = CHILLER
        TYPE               = ELEC-HERM-CENT
        CONDENSER-TYPE     = WATER-COOLED
        CHW-LOOP           = "CHW Loop"
        CW-LOOP            = "CW Loop"
```

```
$ The following at rated conditions
CAPACITY            = 1.2     $ or TONS = 100
RATED-PLR           = 0.95
START-UP-TIME       = .05
ELEC-INPUT-RATIO    = .17
CHW-HEAD            = 20
CW-HEAD            = 15
RATED-CHW-T         = 45
RATED-CHW-FLOW      = 2.4     $ gpm/ton
RATED-COND-T        = 85
RATED-CW-FLOW       = 2.8     $ gpm/ton
..
```

Design Conditions

The next set of keywords describe the design conditions of a chiller:

DESIGN-CHW-T

The leaving chilled-water temperature at the design conditions. If not specified, the program will size the chiller to the temperature required by the chilled-water loop. You should not specify this value unless you want the sizing calculations to be made at a temperature other than the loop temperature.

DESIGN-COND-T

The condensing temperature at the design conditions. You should not specify this value unless you want the sizing calculations to be made at a temperature other than the design sizing temperature. The meaning and the default vary according to condenser type:

- Water-cooled – The entering condenser water temperature. If not specified, the program will size the chiller to the actual temperature delivered by the condenser loop.

- Air-cooled – The entering air temperature. The default is the design-day drybulb temperature at the cooling peak.

- Remote condenser – The saturated condensing temperature. The default is the remote condenser setpoint.

DESIGN-CW-FLOW

For a water-cooled condenser only, is the condenser flow per unit capacity at the actual design conditions. If not specified, by default the design flow is the same as the flow at the rated conditions, as specified by RATED-CW-FLOW or RATED-CW-DT. Please refer to RATED-CW-FLOW for more information on the difference between the rated condenser flow vs. the design (actual) condenser flow.

DESIGN-CW-DT
CW-DT (old keyword)
is an alternative to DESIGN-CW-FLOW, and specifies the temperature rise through the condenser at the design conditions. This keyword overrides the DESIGN-CW-FLOW.

The above are the primary variables that define the rating and design conditions of a conventional electric chiller. Additional variables exists for chillers with remote condensers, and for chillers that can also heat. Those keywords are described in the appropriate sections of the *Dictionary*.

SPECIFIED-AT
no longer used.

Chiller Capacity
The next set of keywords describes the chiller's capacity and operational limits.

CAPACITY
The cooling capacity of the chiller (English: millions of Btu, Metric: kW). The specified capacity corresponds to the rated conditions, i.e. the RATED-CHW-T, RATED-COND-T, RATED-CW-FLOW, and RATED-PLR (centrifugal only).

If you do not specify CAPACITY, the capacity defaults to the design-day chilled water loop load, multiplied by the CAPACITY-RATIO. If no CAPACITY-RATIO is input, the capacity will default to the loop load divided by the number of chillers attached to the loop.

TONS
for English units only, specifies the capacity in tons. This is an alternative to CAPACITY, and gives identical results.

CAPACITY-RATIO
The fraction of the design-day loop load that the chiller will be sized to meet. This keyword is allowed only if CAPACITY is not specified. If you are defining two chillers of identical size that exactly meet the design loop load, set each chiller's CAPACITY-RATIO to 0.5. To include a 20% safety factor, set each chiller's CAPACITY-RATIO to 0.6. If neither CAPACITY nor CAPACITY-RATIO is specified, the chiller capacity will default to the loop capacity divided by the number of chillers attached to the loop.

Note that the circulation-loop also has a sizing safety factor, LOOP-SIZE-RATIO. If the loop's sizing ratio is 1.2, and the capacity-ratio is 0.6, then the chiller will be sized to 1.2*0.6 = 0.72 of the peak design-day load. The SYSTEM:SIZING-RATIO and SYSTEM:COOL-SIZING-RATI also act to increase the equipment capacity.

MAX-RATIO
No longer used For centrifugal chillers, this keyword has been replaced with RATED-PLR, which has a different meaning than MAX-RATIO. For all other chiller types, the program assumes that the maximum capacity is identical to the rated capacity, at the rated conditions. At non-rated temperatures and flows, the maximum capacity may be either greater or less than the rated capacity, depending on the conditions.

MIN-RATIO
The minimum fraction of rated load at which the chiller can operate continuously. If the load is between zero and MIN-RATIO the chiller will cycle on and off, and will operate at the MIN-RATIO when on. When cycling, the program degrades the chiller's efficiency by prorating a portion of the START-UP-TIME to the net chiller load. See START-UP-TIME for more information.

CAPACITY-FT
Takes the U-name of a curve that adjusts the capacity of the chiller as a function of the leaving evaporator water temperature and the condenser temperature. This curve is usually normalized to 1.0 at the rated conditions (RATED-CHW-T, RATED-COND-T, etc.), although this is not mandatory.

The meaning of condenser temperature varies according to the type of condenser:

- <u>Water-cooled</u> – the entering condenser water temperature (leaving cooling-tower temperature). For condenser flows other than the RATED-CW-FLOW, the program will bias the entering condenser

temperature to account for the off-rated flow. Refer to the keyword RATED-CW-FLOW for more information.

- <u>Integral air-cooled</u> – the outdoor air drybulb temperature

- <u>Remote condenser, air-cooled or evaporative</u> – the saturated condensing temperature

START-UP-TIME

The number of hours of equivalent full-load time required to bring the chiller on-line. For example, if it takes the equivalent of 5 minutes of full load fuel consumption to bring an absorption chiller on-line, then this entry should be 5 minutes / 60 min/hr = 0.0833 hours.

Chiller Energy Consumption

The next set of keywords describe the chiller energy consumption. Included here are keywords with significant changes or clarifications. Refer to the Dictionary for the complete list. Not all keywords are used for every chiller type. For example, an electric chiller does not consume any heat or fuel and so does not have an HIR. However, an absorption chiller may have electrical usage, such as for a spray pump, and the electrical consumption of this pump may vary with load. Consequently, the heat- and fuel-chillers use both the EIR and HIR set of keywords

The program uses the following relationship to calculate the electricity input to the chiller each hour:

$$Cap_{hour} = Capacity * CAPf(t1,t2)$$
$$PLR = Load / Cap_{hour}$$
$$dT = t2 - t1$$
$$Elec_{hour} = Cap_{hour} * EIR * EIRf(t1,t2) * EIRf(PLR,dT) / 3413 \text{ Btu/kW}$$

where

Cap_{hour}	hourly capacity, Btuh
Capacity	rated capacity, Btuh
CAPf(t1,t2)	correction to capacity for temperatures, curve CAP-FT
t1	leaving chilled-water temperature, °F
t2	condenser temperature, °F
PLR	Part load ratio
Load	Hourly load, Btuh
dT	Temperature differential across chiller, °F
$Elec_{hour}$	electric input to the chiller, kW
EIR	rated electric input ratio
EIRf(t1,t2)	correction to EIR for temperatures, curve EIR-FT
EIRf(PLR,dT)	correction to EIR for part-load ratio and dT, curve EIR-FPLR

The meaning of the condenser temperature (t2) varies according to the type of condenser:

- <u>Water-cooled</u> – the entering condenser water temperature (leaving cooling-tower temperature). Note that, for condenser flows other than the rated flow, the entering condenser temperature is biased based on leaving temperature to correct the error in the curves that would result otherwise.

- <u>Air-cooled</u> – the outdoor air drybulb temperature

- Remote condenser – the saturated condensing temperature

If you change any one of the above curves you should either change the others or verify that they are reasonable over the expected range of operating conditions.

Thermal energy consumption of absorption and engine chillers is calculated in an identical manner. However the calculation for electric consumption is different, as the program assumes that full-load power consumption does not vary as a function of hourly capacity:

$$\text{Elec}_{hour} = \text{Cap}_{rated} * EIR * EIRf(t1,t2) * EIRf(PLR,dT) / 3413 \text{ Btu/kW}$$

where Cap_{rated} is the rated capacity, which does not vary hourly. Note that these chillers do not have default curves for EIRf(t1,t2) and EIRf(PLR,dT), so that electric consumption has no dependence on operating temperatures or load. Power consumption is then constant all hours:

$$\text{Elec}_{hour} = \text{Cap}_{rated} * EIR / 3413 \text{ Btu/kW}$$

ELEC-INPUT-RATIO
The electric input ratio (EIR) is the ratio of electric input power to capacity (i.e., the inverse of the coefficient of performance (COP)). The EIR is dimensionless, so the same units for input and capacity should be used. The EIR must correspond to the rated conditions, i.e. the RATED-CHW-T, RATED-COND-T, RATED-CW-FLOW, and RATED-PLR. If you change any of the rated conditions, then you should also specify the EIR at the new conditions.

This keyword is the value that the program uses in all hourly calculations. As an alternative, you may enter either the POWER (together with capacity), KW/TON (english units only), ENERGY-EFF-RATIO, or COEF-OF-PERFOR. The program will translate any of these alternative inputs into the ELEC-INPUT-RATIO.

For absorption chillers (TYPE = ABSOR-1, ABSOR-2 or GAS-ABSOR), ELEC-INPUT-RATIO includes the primary power consumption of the chiller and the electrical power consumption of the solution pumps. For these chillers, the program will override the ELEC-INPUT-RATIO if you specify either POWER and/or GAS-COMB-FAN-KW. In this case, the program will recalculate the ELEC-INPUT-RATIO as (POWER + GAS-COMB-FAN-KW) * 3413 Btu/kW / (CAPACITY*106). Note that GAS-COMB-FAN-KW is the combustion blower power for the gas-fired chiller, and applies only to that chiller type.

POWER
is an alternative to ELEC-INPUT-RATIO, and is the power consumption of the chiller at the rated conditions (compressor plus auxiliary consumption). When using POWER, you must also specify CAPACITY (or TONS). The program will calculate the ELEC-INPUT-RATIO as a function of these two values.

KW/TON
is an alternative to ELEC-INPUT-RATIO, and is the ratio of the rated power consumption (kW) divided by the rated capacity of the chiller in tons (english units only; not valid for metric input). The program will translate this value into the ELEC-INPUT-RATIO.

ENERGY-EFF-RATIO
is an alternative to ELEC-INPUT-RATIO, and is the ratio of the rated capacity of the chiller (Btu) divided by the rated power consumption of the chiller in Watts (english units only; not valid for metric input). The program will translate this value into the ELEC-INPUT-RATIO.

COEF-OF-PERFOR

For electric chillers, is an alternative to ELEC-INPUT-RATIO, and is the ratio of the rated capacity of the chiller (Btu) divided by the rated power consumption of the chiller (Btu). The program will translate this value into the ELEC-INPUT-RATIO.

For heat-driven chillers (absorption, engine), is an alternative to HEAT-INPUT-RATIO, and is the ratio of the rated capacity of the chiller (Btu) divided by the rated heat consumption of the chiller (Btu, higher heating value for gas-fired and engine). The program will translate this value into the HEAT-INPUT-RATIO.

EIR-FT

Takes the U-name of a curve that adjusts the electric input ratio as a function of the leaving chilled water temperature and the condenser temperature. This curve is usually normalized to 1.0 at the ARI point (RATED-CHW-T, RATED-COND-T, etc.), although this is not mandatory.

The meaning of condenser temperature varies according to the type of condenser:

- Water-cooled – the entering condenser water temperature (leaving cooling-tower temperature). For condenser flows other than the RATED-CW-FLOW, the program will bias the entering condenser temperature to account for the off-rated flow. Refer to the keyword RATED-CW-FLOW for more information on this topic.

- Air-cooled – the outdoor air drybulb temperature

- Remote condenser – the saturated condensing temperature

EIR-FPLR

Takes the U-name of a curve that adjusts the electric input ratio as a function of

The part load ratio (PLR) – The PLR is defined as the ratio of the hourly load to the hourly capacity; Load / Cap_{hour}

The evaporator/condenser dT - The temperature differential between the condenser and leaving chilled-water. The meaning of the condenser temperature varies according to condenser type.

For most chillers, the dT has a relatively small effect on part-load performance. However, for variable-speed centrifugal chillers, the effect of dT is as important as the PLR. This is because the pressure rise across the impeller is proportional to the square of the impeller's speed. Unless some form of condenser temperature relief and/or chilled water temperature reset is employed to reduce the temperature (and pressure) differential across the chiller at part load, the impeller may have to run at close to full speed even at very low loads. As a result, the performance of a variable-speed chiller may not be significantly different than that of a constant-speed chiller.

To model power consumption as a function of the PLR only, use a CURVE-FIT of TYPE = QUADRATIC or CUBIC. To model as a function of both PLR and dT, use a BI-QUADRATIC-RATIO&DT curve. The curve is usually normalized to 1.0 at full load and the rated temperature differential, although this is not mandatory.

Note that, for centrifugal chillers, 'full load' is defined as the 'maximum capacity', not the 'design capacity'. Refer to the RATED-PLR keyword for more information.

HEAT-INPUT-RATIO

For heat or fuel-powered chillers, is the ratio of heat input to chiller cooling capacity at full load (i.e, at the rated conditions). Note that this is a dimensionless ratio, so you must convert heat input and cooling capacity to the same units before dividing. For fuel-driven chillers, the heat input is normally at the higher-heating value of the fuel.

The HIR must correspond to the rated conditions, i.e. the RATED-CHW-T, RATED-COND-T, and RATED-CW-FLOW. If you change any of the rated conditions, then you should also change the HIR.

HEAT-INPUT
is an alternative to HEAT-INPUT-RATIO, and is the heat/fuel consumption of the chiller at the rated conditions.. When using HEAT-INPUT, you must also specify CAPACITY (or TONS). The program will calculate the HEAT-INPUT-RATIO as a function of these two values. For fuel-driven chillers, the heat input is normally at the higher-heating value of the fuel.

HIR-FT
Takes the U-name of a curve that modifies the chiller HIR as a function of the exiting chilled water temperature and the entering condenser water temperature. This curve is usually normalized to 1.0 at the ARI rating point, although this is not necessary.

The meaning of condenser temperature varies according to the type of condenser:

Water-cooled – the entering condenser water temperature (leaving cooling-tower temperature). For condenser flows other than the RATED-CW-FLOW, the program will bias the entering condenser temperature to account for the off-rated flow. Refer to the keyword RATED-CW-FLOW for more information on this topic.

Air-cooled – the outdoor air drybulb temperature

Remote condenser – the saturated condensing temperature

HIR-FPLR
Takes the U-name of a curve that gives the chiller HIR as a function of:

The part load ratio (PLR) – The PLR is defined as the ratio of the hourly load to the hourly capacity; Load / Cap_{hour}

The temperature differential between the condenser and leaving chilled-water (dT) – The meaning of the condenser temperature varies according to condenser type.

For absorption and engine chillers, the dT has a negligible effect on part-load performance. This relationship is most valid for variable-speed centrifugal chillers (see EIR-FPLR). It is preserved for HIR-FPLR in the event that an engine is used to drive a centrifugal compressor. In this case, the required engine speed, and resulting compressor efficiency, is highly dependent on the dT.

To model power consumption as a function of the PLR only, use a CURVE-FIT of TYPE = QUADRATIC or CUBIC. To model as a function of both PLR and dT, use a BI-QUADRATIC-RATIO&DT curve. The curve is usually normalized to 1.0 at full load and the rated temperature differential, although this is not mandatory.

Chiller Loop Attachment
The following keywords describe how the chiller is attached to a chilled-water loop. If the chiller evaporator has a dedicated pump in a equipment loop, the pump is attached to the chiller from within the chiller command.

CHW-LOOP
Takes the U-name of the primary CHW loop to which this chiller is attached.

CHW-SERIES-LOCN
The CHW-LOOP can be configured to model chillers in either a parallel configuration (the default), two chillers in series, or multiple chillers in a series/parallel configuration (see *Waterside Equipment in Parallel or Series*). For all series and series/parallel configurations, this is a required entry specifying the location of this chiller (evaporator only; chiller condensers on the same loop are always modeled in parallel):

DOWNSTREAM   specifies that this chiller is downstream of another chiller. More than one chiller may be at the downstream location (series/parallel).

UPSTREAM   specifies that this chiller is upstream of another chiller. More than one chiller may be at the upstream location (series/parallel).

For centrifugal chillers, the manufacturer usually adjusts the number of passes through the evaporator in accordance with the evaporator's design temperature drop. DOE-2 recognizes this practice, and adjusts the default CHW-HEAD and RATED-CHW-FLOW as a function of the CIRCULATION-LOOP:LOOP-DESIGN-DT and if the chiller is in series with another chiller.

CHW-HEAD
The head loss through the chiller at the RATED-CHW-FLOW or RATED-CHW-DT.

For centrifugal chillers, the manufacturer usually adjusts the number of passes through the evaporator in accordance with the evaporator's design temperature drop. DOE-2 recognizes this practice, and adjusts the default CHW-HEAD and RATED-CHW-FLOW as a function of the CIRCULATION-LOOP:LOOP-DESIGN-DT and if the chiller is in series with another chiller.

CHW-STATIC-HEAD
The static head of the chiller (non-varying with flow). Normally, this value should be allowed to default to zero.

CHW-PUMP
Takes the U-name of a PUMP directly attached to the chiller's evaporator. Usually, this pump will be a equipment-recirculation pump and will act to decouple the flow of the chiller from the loop. In this case, the pump may have CHW-FLOW-CTRL = CONSTANT-FLOW or VARIABLE-FLOW, and will remove the chiller evaporator head requirement from the primary loop.

If the loop does not have its own pumps, then this pump will also power the loop. In this case, the head of this pump will be the sum of the maximum coil head, the loop distribution head (including static head), and the chiller's evaporator head. The hourly flow of the pump (and chiller) will be determined based on the loop flow and the number of other chillers running (CHW-FLOW-CTRL does not apply in this case, however the CHW-MIN-FLOW will act as a lower limit on pump flow).

If you do not specify the capacity of the pump, the pump will be sized on the basis of the CHW-MAX-FLOW, defined as the ratio of the maximum allowable flow to the rated flow.

The CHW-PUMP is assumed to be external to the chiller, so its pump heat is included in the net loop load in the reports, and its heat increases the cooling load of the attached chiller. The exception to this is the chilled-water pump attached to a loop-to-loop chiller. This pump is treated as internal to the chiller, as it must run whenever the chiller runs, even if the CHW is loop is off and the chiller is only providing heating. For this chiller the chilled-water pump heat is not included in the net loop load, nor the reported load on the chiller (the cooling load in the chiller hourly-report does include this heat).

CHW-FLOW-CTRL

Takes a code-word that specifies the type of flow through the chiller's evaporator. While many manufacturers recommend that the flow through the evaporator be constant, others have incorporated controls that allow the chiller to operate safely with variable flow. This keyword applies only when the CHW-PUMP is acting as a equipment-recirculation pump. If the CHW-PUMP is also powering the loop, or the chiller does not have a pump, then this keyword is ignored.

CONSTANT-FLOW   Indicates that the evaporator flow is independent of the chiller load. Note that unless a CHW-PUMP exists the flow through the chiller evaporator will depend on the primary loop flow. For example, if the flow in the primary loop is variable, then the flow through the chiller will also be variable.

VARIABLE-FLOW   The evaporator flow varies linearly with the chiller load.

CHW-MIN-FLOW

When the chiller has a CHW-PUMP, specifies the minimum allowable fraction of the design flow through the evaporator. Typically, the minimum flow should be above the point where the flow transitions from turbulent to laminar.

Naturally, this keyword applies only when the flow through the chiller is variable. Variable-flow arises in one of two situations:

- The CHW-PUMP acts as a recirculation pump (the loop has its own pump) and the CHW-FLOW-CTRL = VARIABLE-FLOW. In this case, pump flow will modulate to match the assigned loop flow, subject to the minimum allowed flow.

- The loop does not have its own pump. In this case, the chiller's pump is also powering the loop, and its flow is determined by the loop flow. A bypass valve modulates to prevent the flow from dropping below the minimum.

CHW-MAX-FLOW

specifies the maximum flow allowed through the chiller evaporator, expressed as a fraction of the rated flow. If the chiller can handle the load, but the associated flow is greather than the maximum allowed, then the excess flow will be bypassed around the chiller. The chiller's leaving temperature will be depressed to compensate for the bypassed flow, thereby maintaining the required loop setpoint, but at a reduced capacity and efficiency.

For absorption chillers, gas-fired chiller/heaters, and loop-to-loop heat-pumps, the next set of keywords describe how the chiller attaches to a hot-water or steam loop.

HW-LOOP

Takes the U-name of the HW loop to which this chiller is attached. This is a mandatory entry for hot-water/steam-fired absorption chillers, and optional for a gas-fired chiller/heater. Note that a hot water absorption chiller is a demander on the HW-LOOP (similar to a heating coil), whereas a chiller/heater is a supplier to the HW-LOOP (similar to a boiler). As such, a chiller/heater can attach to the same loop types as a boiler.

HW-SERIES-LOCN

This keyword applies only to chiller/heaters. When the HW-LOOP has an EQUIP-CONFIG = SERIES, is a required entry specifying whether this chiller is at the upstream or downstream location.

| DOWNSTREAM | specifies that the chiller is downstream of another chiller or boiler. More than one chiller may be at the downstream location. |
| UPSTREAM | specifies that the chiller is upstream of another chiller or boiler. More than one chiller may be at the upstream location. |

See *Waterside Equipment in Parallel or Series* for more information.

HW-PUMP
Similar to CHW-PUMP. For a hot-water absorption chiller, this pump will overcome the head of the chiller's generator only; it cannot be used to power the hot water loop (This is because the HW attachment for an absorption chiller is a demand on the loop, not a supply). If not specified, the head of the generator will be passed onto the loop.

For a chiller/heater, the chiller is a supplier to the heating loop and is functionally identical to a boiler. A pump attached through this keyword may act either as a equipment-recirculation pump (assuming the loop has its own pumps), or may power the loop (if the loop does not have its own pumps).

If you do not specify the capacity of the pump, the pump will be sized on the basis of the HW-MAX-FLOW, defined as the ratio of the maximum allowable flow to the rated flow.

The HW-PUMP is assumed to be external to the chiller, so its pump heat is included in the net loop load in the reports, and its heat decreases the heating load of the attached chiller. The exception to this is the hot-water pump attached to a loop-to-loop chiller. This pump is treated as internal to the chiller, as it must run whenever the chiller runs, even if the hot-water loop is off and the chiller is only providing cooling. For this chiller, the hot-water pump heat is not included in the net loop load, nor the reported heating load on the chiller (the heating load in the chiller hourly-report does include this heat).

RATED-HW-DT
HW-DT (old keyword)
The temperature change of the hot water through the absorption chiller at the rated conditions. The program uses this keyword to determine the component's flow, which in turn is used to size the equipment-recirculation pump, if any, on the component, and to calculate the hourly pressure drop.. Defaults to the LOOP-DESIGN-DT of the hot water loop.

HW-HEAD
The hot water pressure drop through the absorption chiller at the RATED-HW-DT.

HW-MIN-FLOW
When HW-FLOW-CTRL = VARIABLE-FLOW, specifies the minimum allowable fraction of the design flow through the chiller. Typically, the minimum flow should be above the point where the flow transitions from turbulent to laminar flow.

Naturally, this keyword applies only when the flow through the chiller/heater is variable. Variable-flow arises in one of two situations:

- The HW-PUMP acts as a recirculation pump (the loop has its own pump) and the HW-FLOW-CTRL = VARIABLE-FLOW. In this case, pump flow will modulate to match the assigned loop flow, subject to the minimum allowed flow.

- The loop does not have its own pump. In this case, the chiller/heater's pump is also powering the loop, and its flow is determined by the loop flow. A bypass valve modulates to prevent the flow from dropping below the minimum.

HW-MAX-FLOW

This keyword applies only to chiller/heaters. It specifies the maximum flow allowed through the chiller heating section, expressed as a fraction of the rated flow. If the chiller can handle the load, but the associated flow is greather than the maximum allowed, then the excess flow will be bypassed around the chiller. The chiller's leaving temperature will be raised to compensate for the bypassed flow, thereby maintaining the required loop setpoint, but at a reduced capacity and efficiency.

If a hot-water pump is attached directly to the chiller (HW-PUMP), by default the pump is sized on the basis of the HW-MAX-FLOW and the corresponding head. For example, if the HW-MAX-FLOW is 1.2, and the head at the rated flow is 10, then the head corresponding to the HW-MAX-FLOW is $10 * 1.2^{1.8}$. If the loop does not have a pump, the pump head is further increased by the loop and coil heads.

If the chiller does not have a dedicated hot-water pump, by default the loop pump is sized to the rated HW-HEAD, adjusted by the HW-MAX-FLOW; plus the loop and coil heads. For example, if the HW-HEAD = 10 and HW-MAX-FLOW = 1.1, the design head imposed on the loop by the evaporator is $10 * 1.1^{1.8}$

Water-Cooled Condenser

The following set of keywords describes how the chiller with a water-cooled condenser is attached to a condenser water loop. If the chiller has a dedicated condenser-water pump in a equipment loop, the pump is attached to the chiller from within the PUMP command. These keywords apply only to water-cooled condensers (CONDENSER-TYPE = WATER-COOLED).

Keywords describing the flow at the rated conditions, and the actual flow at the design conditions are described in the section *Rated vs. Design Conditions*.

CW-LOOP

When CONDENSER-TYPE = WATER-COOLED, takes the U-name of the CW loop to which this chiller is attached.

CW-PUMP

Takes the U-name of a PUMP directly attached to the chiller's condenser. This pump may be either a equipment-recirculation pump, or may power the loop. If you have more than one chiller attached to a given CW loop, and the loop does not have a pump, then each chiller must have a condenser pump.

Note: If you are modeling a chiller that primarily cycles on/off for capacity control, it is best to specify the pump here, rather than at the loop level. This is because a condenser pump attached directly to a chiller will cycle on/off with the chiller; a pump specified at the loop level is assumed to operate continuously.

CW-HEAD

The pressure drop through the condenser at the rated conditions. This head corresponds to the RATED-CW-FLOW. If the actual condenser flow, as specified by DESIGN-CW-DT is different than the rated flow, then the head will be adjusted accordingly.

Air-Cooled Condenser

The next set of keywords describe changes to the remote air-cooled condenser. Refer to the Dictionary for the complete list.

Example Input:

```
"Remote Air-Cooled Chiller" = CHILLER
    TYPE               = ELEC-HERM-REC
    CONDENSER-TYPE     = REMOTE-AIR-COOLED
    CHW-LOOP           = "CHW Loop"
    CW-LOOP            = "CW Loop"

    $ Specify the performance and rated conditions
    TONS               = 40.      $ tons
    START-UP-TIME      = .05
    POWER              = 45.      $ kW
    CHW-HEAD           = 6.20
    RATED-CHW-T        = 45.
    RATED-CHW-FLOW     = 2.38     $ gpm/ton
    RATED-COND-T       = 110.

    $ Specify the condenser and rated conditions
    COND-CAPACITY      = 0.70     $ millions of Btu
    SCT-AMB-DT         = 10.4
    COND-FAN-PWR       = 9.5      $ kW
    ..
```

COND-CAPACITY

Specifies the capacity of the condenser at a given rated temperature differential between saturated condensing temperature and ambient drybulb temperature, SCT-AMBIENT-DT. If you do not specify the capacity, it will default to the design heat rejection load of the chiller. The program will not allow you to specify the condenser's capacity unless you also specify the chiller's capacity.

SCT-AMBIENT-DT

Specifies the differential between the saturated condensing temperature and the outdoor drybulb temperature at which the COND-CAPACITY is rated. This keyword is required when the capacity is specified. When autosizing the condenser capacity, the program generates an equivalent value using:

- The saturated condensing temperature – This is specified using the DESIGN-COND-T, if specified, or the remote condenser setpoint temperature.

- The outdoor drybulb temperature – This is specified using the REMOTE-DESIGN-DB, if specified, or the design-day drybulb temperature at which the chiller is sized.

When defaulted, the program will limit the differential to not less than 5F.

REMOTE-DESIGN-DB

When autosizing a condenser, specifies the design drybulb temperature at which the condenser is to operate on the design-day. The default is the design-day outdoor drybulb temperature at which the chiller is sized. The program assumes the condenser capacity is at the temperature differential given by the difference between the:

- The saturated condensing temperature – This is specified using the DESIGN-COND-T, if specified, or the remote condenser setpoint temperature.

- The outdoor drybulb temperature – This is specified using the REMOTE-DESIGN-DB, if specified, or the hourly design-day drybulb temperature.

When defaulted, the program will limit the differential to not less than 5F.

DESIGN-COND-T

When autosizing the chiller/remote condenser, specifies the saturated condensing temperature at which the condenser is to operate on the design-day. The default is the hourly condenser setpoint temperature. The program assumes the condenser capacity is at a temperature differential given by the difference between the:

- The saturated condensing temperature – This is specified using the DESIGN-COND-T, if specified, or the remote condenser setpoint temperature.

- The outdoor drybulb temperature – This is specified using the REMOTE-DESIGN-DB, if specified, or the hourly design-day drybulb temperature.

When defaulted, the program will limit the differential to not less than 5F. For a chiller with a remote condenser, this keyword is common to both components, and affects the sizing of both.

Note that the RATED-COND-T is the saturated-condensing temperature at which the chiller's capacity, power consumption, etc. is specified. See *Rated vs. Design Conditions* for more information.

COND-FAN-PWR

specifies the power consumption of the condenser fan in kW. This is an alternative to COND-FAN-EIR-TD, and can only be specified if you also specify the condenser capacity.

Evaporatively-Cooled Condenser

The next set of keywords highlight the enhancements to the evaporatively-cooled condenser. Refer to the Dictionary for the complete list.

Example Input:

```
"Remote Evap-Cooled Chiller" = CHILLER
   TYPE               = ELEC-HERM-REC
   CONDENSER-TYPE     = REMOTE-EVAP-COOLED
   CHW-LOOP           = "CHW Loop"
   CW-LOOP            = "CW Loop"

   $ Specify the performance and rated conditions
   TONS               = 120.    $ tons
   START-UP-TIME      = .05
   POWER              = 90.     $ kW
   CHW-HEAD           = 10.2
   RATED-CHW-T        = 45.
   RATED-CHW-FLOW     = 2.4     $ gpm/ton
   RATED-COND-T       = 105.

   $ Specify the condenser and rated conditions
   COND-CAPACITY      = 1.9     $ millions of Btu
   COND-FAN-PWR       = 9.5     $ kW
   COND-PUMP-PWR      = 1.7     $ kW
```

```
        REMOTE-RATED-WB    = 72.
        REMOTE-RATED-SCT   = 105.
        ..
```

Capacity

This following set of keywords describe how the condenser capacity is defined.

COND-CAPACITY

Specifies the capacity of the condenser at a given wetbulb temperature and saturated condensing temperature (REMOTE-RATED-WB, REMOTE-RATED-SCT). If you do not specify the capacity, it will default to the design heat rejection load of the chiller. The program will not allow you to specify the condenser's capacity unless you also specify the chiller's capacity.

REMOTE-RATED-WB

Specifies the wetbulb temperature at which the condenser's capacity and power consumption are defined.

REMOTE-RATED-SCT

Specifies the saturated condensing temperature at which the condenser's capacity and power consumption are defined.

REMOTE-DESIGN-WB

When autosizing the remote condenser, specifies the design wetbulb temperature at which the condenser is to be sized on the design-day. The default is the hourly design-day outdoor wetbulb temperature at which the peak condenser capacity occurs.

The program assumes the condenser capacity is at a temperature differential given by the difference between the:

- The saturated condensing temperature – This is specified using the DESIGN-COND-T, if specified, or the remote condenser setpoint temperature.

- The outdoor wetbulb temperature – This is specified using the REMOTE-DESIGN-WB, if specified, or the hourly design-day drybulb temperature.

When defaulted, the program will limit the differential to not less than 5F.

DESIGN-COND-T

When autosizing the chiller/remote condenser, specifies the saturated condensing temperature at which the condenser is to be sized on the design-day. (The chiller also operates at this temperature.) The default is the hourly condenser setpoint temperature. The program assumes the condenser capacity is at a temperature differential given by the difference between the:

- The saturated condensing temperature – This is specified using the DESIGN-COND-T, if specified, or the remote condenser setpoint temperature.

- The outdoor wetbulb temperature – This is specified using the REMOTE-DESIGN-WB, if specified, or the hourly design-day drybulb temperature.

When defaulted, the program will limit the differential to not less than 5F. For a chiller with a remote condenser, this keyword is common to both components, and affects the sizing of both.

COND-CAP-FT

Accepts the U-name of a curve that modifies the rated condenser capacity as a function of the saturated condensing temperature and the wetbulb temperature. This curve is usually normalized to the rated conditions, although this is not mandatory. The default curve is normalized to rated conditions of 105°F saturated condensing temperature and 78°F outdoor wetbulb temperature (40.5°C/25.5°C).

COND-FAN-EIR

specifies the electric input ratio (EIR) of the condenser fan(s), where the EIR is a dimensionless ratio of the fan energy consumption to the condenser capacity:

$$EIRfan = Fan\ power,\ Btu/hr\ /\ Condenser\ capacity,\ Btu/hr$$

You specify the fan EIR at the rated capacity. Since the fan EIR corresponds to the rated capacity, the default EIR corresponds to the default REMOTE-RATED-WB and REMOTE-RATED-SCT. Therefore, if you modify either of the rated temperatures, you should also redefine the fan EIR.

The hourly fan energy is calculated as:

$$kWfan = RatedCap * EIRfan * f(PLR) * Frac$$

where RatedCap is the rated capacity of the chiller, f(PLR) is a curve that modifies fan energy as a function of the condenser part load ratio (COND-PWR-FPLR), and Frac is the fraction of the hour the chiller is operating.

COND-FAN-PWR

specifies the power consumption of the condenser fan in kW. This is an alternative to COND-FAN-EIR, and can only be specified if you also specify the condenser capacity.

COND-PWR-FPLR

accepts the U-name of a curve that modifies the condenser fan energy consumption as a function of the condenser part load ratio.

COND-PUMP-EIR

specifies the electric input ratio (EIR) of the condenser spray pump(s), where the EIR is a dimensionless ratio of the pump energy consumption to the condenser capacity:

$$EIRpump = Pump\ power,\ Btu\ /\ Condenser\ capacity,\ Btu$$

You specify the pump EIR at the rated capacity. Since the pump EIR corresponds to the rated capacity, the default EIR corresponds to the default REMOTE-RATED-WB and REMOTE-RATED-SCT. Therefore, if you modify either of the rated temperatures, you should also redefine the pump EIR.

The condenser pump energy is independent of condenser load, but will cycle on/off if the chiller is also cycling.

COND-PUMP-PWR

specifies the power consumption of the condenser pump in kW. This is an alternative to COND-PUMP-EIR, and can only be specified if you also specify the condenser capacity.

Gas-Fired Absorption Chiller (GAS-ABSOR)

The following highlights changes made to the gas-fired chiller/heater. Please refer to the Dictionary for the complete list.

A gas-fired chiller provides cooling in a manner similar to a more conventional steam/hot-water fired absorption chiller. The condennser is always water cooled.

Optionally, the chiller may also act as a boiler, and provide heating to a hot water loop (chiller/heater). In this case, the chiller is attached to a HW loop in addition to a CHW loop. The gas burner is sized to the cooling capacity, and when the chiller is not fully loaded the surplus burner capacity is available for heating. In the heating mode, a chiller/heater acts identically to a boiler, and may be sequenced with other boilers and chiller/heaters via an EQUIP-CTRL sequence.

When the CAPACITY is allowed to default, the program sizes the chiller on the basis of the peak design-day heating or cooling load, whichever requires the largest machine. Note, however, that this may not ensure that the machine is sized properly for an intermediate day in which significant heating and cooling loads coincide (during peak heating, a cooling load may be non-existent, and vice versa). Since cooling loads take precedence, the heating loop may have insufficient capacity. For this reason, you should always review report PS-D or PS-H for the hot-water loop, and verify whether any significant overloads exist. If so, then you must manually increase the chiller CAPACITY or CAPACITY-RATIO, or specify a boiler and its CAPACITY or CAPACITY-RATIO.

HEAT/COOL-CAP
Is the ratio of the heating capacity to the cooling capacity at the rated conditions.

The chiller's CAPACITY is the cooling capacity at the rated conditions of temperature and flow. At the ARI standard rated conditions, the heating capacity is usually very close to the cooling CAPACITY. If, however, the heating capacity was only 80% of the cooling capacity, then this keyword would have a value of 0.8

GAS-HCAP-FPLRC
Takes the U-name of a curve that modifies the heating capacity as a function of the cooling part load ratio. Cooling loads take precedence, and only the surplus burner capacity is available for heating.

Example Input:

```
    "Chiller/Heater" = CHILLER
       TYPE              = GAS-ABSOR
       CHW-LOOP          = "Chilled Water Loop"
       HW-LOOP           = "Hot Water Loop"
       CW-LOOP           = "Tower Loop"
       CW-FLOW-CTRL      = VARIABLE-FLOW

       $ Specify the performance and rated conditions
       TONS              = 192
       HEAT/COOL-CAP     = 0.954
       START-UP-TIME     = .05
       COEF-OF-PERFOR    = 1.03
       POWER             = 6.1      $ kW
       CHW-HEAD          = 10.6
       RATED-CHW-T       = 44.
       RATED-CHW-FLOW    = 2.40     $ gpm/ton
       CW-HEAD           = 20.1
       RATED-COND-T      = 85.
       RATED-CW-FLOW     = 4.41
       HW-HEAD           = 9.8
       RATED-HW-DT       = 10.
       ..
```

Engine-Driven Chiller (ENGNE)

Engine-drive chillers may be either water-cooled or air-cooled, however default performance data is available only for water-cooled. For air-cooled, the program will require input for the HEAT-INPUT-RATIO.

Air-to-Water Heat-Pump (HEAT-PUMP, AIR-COOLED)

The following summarizes the changes made to keywords for an air-to-water heat pump. Please refer to the Dictionary for the complete list.

Since this type of chiller is common in Europe, but not in the United States, the default performance curves are normalized at the Eurovent rating conditions, rather than ARI. However, this has no effect on English specifications as long as the ELEC-INPUT-RATIO, etc. are specified at consistent set of rating conditions.

RATED-HW-T

The leaving hot-water temperature at the rated HEAT/COOL-CAP and heating efficiency. This is the value at which the heating mode performance curves are usually normalized, although this is not necessary.

RATED-COND-T-HT

The outdoor temperature at the rated HEAT/COOL-CAP and heating efficiency. This is the value at which the heating mode performance curves are usually normalized, although this is not necessary.

DESIGN-HW-T

The leaving hot-water temperature at the heating design conditions. If not specified, the program will size the chiller to the heating temperature required by the 2-pipe loop.

DESIGN-COND-T-HT

The outdoor temperature at the heating design conditions. The default is the design-day drybulb temperature at the heating peak.

HEAT/COOL-CAP

Is the ratio of the heating capacity to the cooling capacity at the rated conditions.

The chiller's CAPACITY is the cooling capacity at the rated conditions. At the Eurovent standard heating rating conditions, the heating capacity is usually very close to the cooling capacity. If, however, the heating capacity was only 80% of the cooling capacity, then this keyword would have a value of 0.8

When the CAPACITY is allowed to default, the chiller will be sized on the basis of either the peak design-day heating or cooling load, whichever requires the largest machine.

HEAT-CAP-FT

(No frost) Takes the U-name of a curve the gives the heating capacity of the chiller as a function of the leaving hot water temperature and the entering air temperature, *when the air temperature is warm enough to prevent frost build-up on the heat-exchanger.* The value of the curve is usually normalized to 1.0 at rated conditions, but this is not mandatory; the program will normalize the curve internally.

At air temperatures above 39°F (4°C), frost does not typically build up on the heat-exchanger. Below this temperature, frost build-up may be significant, and a defrost cycle is necessary. The no-frost/frost transition cannot be accurately modeled using a single bi-quadratic curve, so two curves are used.

HEAT-CAP-FT-FRST

Takes the U-name of a curve the gives the heating capacity of the chiller as a function of the leaving hot water temperature and the entering air temperature, *when the air temperature is cool enough that frost forms on the heat-exchanger.* This curve is usually normalized to 1.0 at the ARI or Eurovent rating point, although this is not mandatory.

At air temperatures above 39°F (4°C), frost does not typically build up on the heat-exchanger. Below this temperature, frost build-up may be significant, and a defrost cycle is necessary. The no-frost/frost transition cannot be accurately modeled using a single bi-quadratic curve, so two curves are used.

HEAT-EIR

The ratio of electric input power to heating capcacity at the heating rated conditions. The HEAT-EIR is dimensionless, so the same units for electric input and capacity must be used in the calculation.

This keyword is the value that the program uses in all hourly calculations. As an alternative, you may enter either the HEAT-POWER (together with capacity), HEAT-EER, or HEAT-COP. The program will translate any of these alternative inputs into the HEAT-EIR.

The program uses the following relationship to calculate the electricity input to the chiller each hour when heating:

$$Cap_{hour} = Capacity * Heat/Cool\text{-}Cap * Cap\ f(Thws, OAT)$$
$$dT = Thws - OAT$$
$$Elec_{hour} = Cap_{hour} * EIR * EIR\ f(PLR, dT) * EIR\ f(Thws, OAT)$$

where

Thws	leaving hot-water temperature
OAT	entering outdoor air temperature
Cap_{hour}	hourly heating capacity
Capacity	rated cooling capacity, CAPACITY
Heat/Cool-Cap	ratio of rated heating capacity to rated cooling capacity, HEAT/COOL-CAP
Cap f(Thws,OAT)	correction to capacity for temperatures, curve HEAT-CAP-FT
$Elec_{hour}$	electric input to the chiller
EIR	rated electric input ratio, HEAT-EIR
EIR f(PLR,dT)	correction to EIR for part-load ratio, curve HEAT-EIR-FPLR
EIR f(Thws,OAT)	correction to EIR for temperatures, curve HEAT-EIR-FT

If you change any one of the above curves you should either change the others or verify that they are reasonable over the expected range of operating conditions.

HEAT-POWER

is an alternative to HEAT-EIR, and is the power consumption of the chiller at the rated heating conditions (compressor plus auxiliary consumption). When using HEAT-POWER, you must also specify CAPACITY. The program will calculate the HEAT-EIR as a function of these two values, and the HEAT/COOL-CAP.

HEAT-EER

is an alternative to HEAT-EIR, and is the ratio of the rated heating capacity of the chiller (Btu) divided by the rated heating power consumption of the chiller in Watts (Btu/Watts, english units only; not valid for metric input). The program will translate this value into the HEAT-EIR.

HEAT-COP

is an alternative to HEAT-EIR, and is the ratio of the rated heating capacity of the chiller (Btu) divided by the rated power consumption of the chiller (Btu). The program will translate this value into the HEAT-EIR.

HEAT-EIR-FT

(No frost) Takes the U-name of a curve that adjusts the HEAT-EIR as a function of the leaving hot water temperature and the entering air temperature, *when the air temperature is warm enough to prevent frost build-up on the heat-exchanger.* The value of the curve is usually normalized to 1.0 at rated conditions, but this is not mandatory; the program will normalize the curve internally.

At air temperatures above 39°F (4°C), frost does not typically build up on the heat-exchanger. Below this temperature, frost build-up may be significant, and a defrost cycle is necessary. The no-frost/frost transition cannot be accurately modeled using a single bi-quadratic curve, so two curves are used.

HEAT-EIR-FT-FRST

(frost) Takes the U-name of a curve that adjusts the HEAT-EIR as a function of the leaving hot water temperature and the entering air temperature, *when the air temperature is cool enough that frost forms on the heat-exchanger.* The value of the curve is usually normalized to 1.0 at rated conditions, but this is not mandatory; the program will normalize the curve internally. However, the value of the curve must be consistent with HEAT-EIR-FT-FRST.

At air temperatures above 39°F (4°C), frost does not typically build up on the heat-exchanger. Below this temperature, frost build-up may be significant, and a defrost cycle is necessary. The no-frost/frost transition cannot be accurately modeled using a single bi-quadratic curve, so two curves are used.

HEAT-EIR-FPLR

Takes the U-name of a curve that adjusts the HEAT-EIR as a function of the heating part load ratio, and possibly the temperature differential between the hot-water supply temperature and the entering air temperature. The curve is usually normalized to 1.0 at full load and rated outdoor heating temperature, although this is not mandatory.

Example Input:

```
"Chiller HeatPump" = CHILLER
   TYPE               = HEAT-PUMP
   CONDENSER-TYPE     = AIR-COOLED
   CHW-LOOP           = "CHW Loop"

   $ Specify the performance and rated conditions
   CAPACITY           = .276     $ millions of Btu
   START-UP-TIME      = .05
   POWER              = 35.9     $ kW
   CHW-HEAD           = 4.2
   RATED-CHW-T        = 45.
   RATED-CHW-FLOW     = 1.48     $ gpm/ton
   RATED-COND-T       = 103.56

   HEAT/COOL-CAP      = 0.8208
   HEAT-POWER         = 27.9     $ kW
   RATED-HW-T         = 119.
   RATED-COND-T-HT    = 35.0
   ..
```

Well-Water-to-Water Heat-Pump (HEAT-PUMP, WATER-COOLED)

The following summarizes the enhancements to the well-water-to-water heat pump. Please refer to the Dictionary for the complete list of applicable keywords.

Since this type of chiller is common in Europe, but not in the United States, the default performance curves are normalized at the Eurovent rating conditions, rather than ARI. However, this does not affect English specifications, as long as everything is specified at a consistent set of rating conditions.

RATED-HW-T
The leaving hot-water temperature at the rated HEAT/COOL-CAP and heating efficiency. This is the value at which the heating mode performance curves are usually normalized, although this is not necessary.

RATED-COND-T-HT
The outdoor temperature at the rated HEAT/COOL-CAP and heating efficiency. This is the value at which the heating mode performance curves are usually normalized, although this is not necessary.

RATED-HT/CL-FLOW
specifies the ratio of the condenser flow during heating to the flow during cooling at the rated conditions. As an alternative, you may specify the RATED-CW-DT-HT.

Heating and cooling performance are usually rated at a constant CW-LOOP temperature change of 9°F (5°C). However, because the heat taken or rejected to the CW-LOOP is not the same in both modes, the rated flow used to develop the performance curves is different in each case; usually with the heating flow smaller than the cooling flow.

Normally, you should not change the default value of this keyword unless you are also specifying the heat-pump performance curves, and the curves are normalized to a different value.

RATED-CW-DT-HT
as an alternative to RATED-HT-CL-FLOW, specifies the condenser temperature drop during the heating mode.

DESIGN-HW-T
The leaving hot-water temperature at the heating design conditions. If not specified, the program will size the chiller to the heating temperature required by the 2-pipe loop.

DESIGN-COND-T-HT
The entering WLHP temperature at the design heating conditions. If not specified, the program will use the design-day WLHP temperature at the heating peak.

HEAT/COOL-CAP
Is the ratio of the heating capacity to the cooling capacity at the rated conditions.

The chiller's CAPACITY is the cooling capacity at the rated conditions. At the Eurovent standard heating rating conditions, the heating capacity is usually very close to the cooling capacity. If, however, the heating capacity is only 80% of the cooling capacity, then this keyword would have a value of 0.8

When the CAPACITY is allowed to default, the chiller will be sized on the basis of either the peak design-day heating or cooling load, whichever requires the largest machine.

RATED-CW-FLOW
For a water-cooled condenser, specifies the condenser flow at the rated conditions in gpm/ton (L/S-KW). As an alternative, you may specify the RATED-CW-DT instead. While the RATED-CW-FLOW corresponds to the condtions at which the CAPACITY, ELEC-INPUT-RATIO, etc. are specified, the actual condenser flow may be different (see DESIGN-CW-** variables).

Why is this keyword relevant? Chiller manufacturers normally report performance as a function of the *entering* condenser water temperature, and the DOE-2 performance curves conform to this convention. However, the *leaving* condenser water temperature is actually a more important determinant of chiller performance, and must be taken into account when simulating a chiller with a condenser flow other than the rated flow. The program uses this keyword to bias the entering condenser temperature for off-rated and/or variable condenser flows.

RATED-CW-DT
as an alternative to RATED-CW-FLOW, specifies the condenser temperature rise at the rated conditions. The rated flow will then be calculated as a function of this value and the power consumption of the chiller.

DESIGN-CW-DT
The temperature change of the WLHP water when in the cooling mode, at the design conditions. The default is 90°F (32°C) minus the CW-LOOP:DESIGN-COOL-T. For example, if the design cooling temperature of the WLHP loop is 60°F, then the design temperature change will be 30°F.

The expansion valve of the heat pump is sized for the high pressure differential that normally exists in the heating mode. In the cooling mode, if 60°F water were to enter the heat pump with only a 10°F rise, then the condensing pressure would be too low to maintain refrigerant flow through the expansion valve. For this reason, flow is normally reduced through the condenser when in the cooling mode. This is accomplished via a solenoid valve in parallel with a restricting valve. During cooling, the solenoid valve is closed, and condenser flow is restricted through the balance valve (thereby achieving the CW-DT). During heating, the solenoid valve is open, allowing full flow.

DESIGN-CW-DT-HT
The temperature change of the WLHP water when in the heating mode, at the design conditions. If not specified, the flow will be the rated heating flow.

The expansion valve of the heat pump is sized for the high pressure differential that normally exists in the heating mode. In the cooling mode, if 60°F water were to enter the heat pump with only a 10°F rise, then the condensing pressure would be too low to maintain refrigerant flow through the expansion valve. For this reason, flow is normally reduced through the condenser when in the cooling mode. This is accomplished via a solenoid valve in parallel with a restricting valve. During cooling, the solenoid valve is closed, and condenser flow is restricted through the balance valve (thereby achieving the DESIGN-CW-DT). During heating, the solenoid valve is open, allowing full flow.

HEAT-CAP-FT
Takes the U-name of a curve the gives the heating capacity of the chiller as a function of the leaving hot water temperature and the entering WLHP temperature. This curve is usually normalized to 1.0 at the ARI or Eurovent rating point, although this is not mandatory.

HEAT-EIR
The ratio of electric input power to heating capcacity at the rated heating conditions. The HEAT-EIR is dimensionless, so that the same units for electric input and capacity must be used when calculating it.

The program uses the following relationship to calculate the electricity input to the chiller each hour when heating:

$$\text{Cap}_{hour} = \text{Capacity} * \text{Heat/Coo-Cap} * \text{Cap f(Thws,Twws)}$$
$$dT = \text{Thws - Twws}$$
$$\text{Elec}_{hour} = \text{Cap}_{hour} * \text{EIR} * \text{EIR f(PLR,dT)} * \text{EIR f(Thws,Twws)}$$

where

Thws	leaving hot-water temperature
Twws	entering WLHP water temperature
Cap_{hour}	hourly heating capacity
Capacity	rated cooling capacity, CAPACITY
Heat/Cool-Cap	ratio of rated heating capacity to rated cooling capacity, HEAT/COOL-CAP
Cap f(Thws,Twws)	correction to capacity for temperatures, curve HEAT-CAP-FT
$Elec_{hour}$	electric input to the chiller
EIR	rated electric input ratio, HEAT-EIR
EIR f(PLR,dT)	correction to EIR for part-load ratio, curve HEAT-EIR-FPLR
EIR f(Thws,Twws)	correction to EIR for temperatures, curve HEAT-EIR-FT

If you change any one of the above curves you should either change the others or verify that they are reasonable over the expected range of operating conditions.

HEAT-POWER
is an alternative to HEAT-EIR, and is the power consumption of the chiller at the rated heating conditions (compressor plus auxiliary consumption). When using HEAT-POWER, you must also specify CAPACITY. The program will calculate the HEAT-EIR as a function of these two values, and the HEAT/COOL-CAP.

HEAT-EER
is an alternative to HEAT-EIR, and is the ratio of the rated heating capacity of the chiller (Btu) divided by the rated heating power consumption of the chiller in Watts (Btu/Watts, english units only; not valid for metric input). The program will translate this value into the HEAT-EIR.

HEAT-COP
is an alternative to HEAT-EIR, and is the ratio of the rated heating capacity of the chiller (Btu) divided by the rated power consumption of the chiller (Btu). The program will translate this value into the HEAT-EIR.

HEAT-EIR-FT
Takes the U-name of a curve that adjusts the HEAT-EIR as a function of the leaving hot water temperature and the entering WLHP temperature. This curve is usually normalized to 1.0 at the ARI or Eurovent rating point, although this is not mandatory.

HEAT-EIR-FPLR
Takes the U-name of a curve that adjusts the HEAT-EIR as a function of the heating part load ratio, and possibly the temperature differential between the hot-water supply temperature and the entering well temperature temperature. The curve is usually normalized to 1.0 at full load and rated well temperature, although this is not mandatory.

Example Input:

```
"Chiller HeatPump" = CHILLER
   TYPE              = HEAT-PUMP
   CONDENSER-TYPE    = WATER-COOLED
   CHW-LOOP          = "CHW Loop"
   CW-LOOP           = "Well Loop"

   $ Specify the performance and rated conditions
   CAPACITY          = .276    $ millions of Btu
   START-UP-TIME     = .05
   POWER             = 14.5    $ kW
   CHW-HEAD          = 4.2
   RATED-CHW-T       = 45.
```

```
        RATED-CHW-FLOW      = 1.69     $ gpm/ton
        RATED-COND-T        = 75.0
        RATED-CW-FLOW       = 3.16

        HEAT/COOL-CAP       = 0.93
        HEAT-POWER          = 23.8    $ kW
        RATED-HW-T          = 119.
        RATED-COND-T-HT     = 41.37
        RATED-CW-DT-HT      = 7.25
        ..
```

Loop-to-Loop Heat-Pump (LOOP-TO-LOOP-HP)

This section summarizes the enhancements made to the loop-to-loop heat pump. Please refer to the Dictionary for the complete list of keywords.

Capacity and power consumption at a set of rated conditions are specified in a similar fashion as for a conventional electric chiller (CAPACITY, START-UP-TIME, and ELEC-INPUT-RATIO at the RATED-CHW-T, RATED-COND-T, and RATED-CW-FLOW). Exceptions are noted below:

CHW-HEAD
is the sum of the pressure drop through the chiller evaporator and the evaporator-to-well heat-exchanger. This pressure drop is at the RATED-CHW-FLOW. Since

HW-HEAD
is the sum of the pressure drop through the chiller condenser and the condenser-to-well heat-exchanger.   The pressure drop is at the RATED-HW-DT, or the RATED-CW-DT, or the RATED-CW-FLOW.

CW-HEAD
is the pressure drop through the well-side of the heat-exchangers. The pressure drop is at the RATED-CW-DT, or the RATED-CW-FLOW.

DESIGN-HW-T
The leaving hot-water temperature at the heating design conditions. The default is the same as the DESIGN-HEAT-T of the hot-water loop to which this chiller is attached. (DESIGN-CHW-T is similar, and applies to the CHW loop.)

RATED-HW-DT
The temperature rise through the hot-water/condenser run-around loop at the rated capacity and flow. The program uses this value to calculate the required flow of the hot-water pump. If not specified, the flow is based on either the RATED-CW-DT, or the RATED-CW-FLOW.

DESIGN-WELL-T
The design water temperature provided by the well when the the chiller is cooling-dominated. The default is the temperature provided by the WLHP ground-loop heat-exchanger; as defined by its schedule or the monthly ground temperature. For a given cooling load, the rated capacity of the chiller will increase as this value is increased, if the well temperature no longer allows the condenser heat-exchanger setpoint to be maintained.

DESIGN-WELL-T-HT
The design water temperature provided by the well when the the chiller is heating-dominated. The default is the temperature provided by the WLHP ground-loop heat-exchanger; as defined by its schedule or the monthly ground temperature. For a given cooling load, the rated capacity of the chiller will increase as this value is increased, if the well temperature no longer allows the condenser heat-exchanger setpoint to be maintained.

EVAP-HX-DESIGN-T
No longer used

EVAP-HX-SETPT-T
When the chiller is in the heating-only mode and heat-exchanger IC-EV is adding heat to the evaporator loop, specifies the temperature setpoint of the chilled-water *leaving* the evaporator, i.e. the chilled-water supply temperature. This keyword applies to the *heating-only* mode. In all other modes involving cooling, the heat-exchanger is controlled so that the temperature requirement of the chilled-water loop (chilled-water supply temperature) is met.

The program uses this setpoint, together with the hourly load, UA product and chilled-water flow, to calculate the chilled-water temperature and required well-water flow. Note that this setpoint may not be maintained if the well-water is too cold. For example, if the setpoint is 50°F but the well-water is only 45°F, then it will be impossible to meet the setpoint, and the evaporator temperature will float somewhere below 50°F.

The heating-only energy efficiency may be increased by raising this setpoint, but possibly at the expense of well pumping energy.

EVAP-HX-TD
is the design temperature differential between the chilled-water and well-water streams *entering* the evaporator-side heat-exchanger (IC-EV in the diagrams). This is the differential when the chiller is operating in the heating-only mode, which represents maximum heat-exchanger loading. The program uses this value, together with the rated evaporator load in the heating mode, and the design chilled-water and well-water flows, to calculate the UA product of the heat-exchanger.

EVAP-HX-UA
an alternative to EVAP-HX-TD, specifies the UA product of the evaporator heat-exchanger. You may specify this value only if you also specify the CAPACITY.

COND-HX-SETPT-T
When the chiller is in the cooling-only mode and heat-exchanger IC-CD is removing heat from the condenser (hot-water) loop, specifies the temperature setpoint of the hot-water *leaving* the heat-exchanger and entering the condenser. This keyword applies to the *cooling-only* mode. In all other modes involving heating, the heat-exchanger is controlled so that the temperature requirement of the hot-water loop (hot-water supply temperature) is met.

The program uses this setpoint, together with the hourly load, UA product and chilled-water flow, to calculate the condenser-water temperature and required well-water flow. Note that this temperature may not be maintained if the WLHP-water is too warm. For example, if the setpoint is 75°F but the chiller is attached to a lake that peaks at 80°F, then it will be impossible to meet the setpoint.

The cooling-only energy efficiency may be increased by lowering this setpoint, but possibly at the expense of well pumping energy.

COND-HX-TD
is the design temperature differential between the hot-water and well-water streams *entering* the condenser-side heat-exchanger (IC-CD in the diagrams). This is the differential when the chiller is operating in the cooling-only mode, which represents maximum heat-exchanger loading. The program uses this value, together with the design condenser load in the cooling mode, and the design hot-water and well-water flows, to calculate the UA product of the heat-exchanger.

COND-HX-UA
an alternative to COND-HX-TD, specifies the UA product of the evaporator heat-exchanger. You may specify this value only if you also specify the CAPACITY.

EVAP-HX-DESIGN-T

No longer used

Example Input:

```
"3-Loop HeatPump" = CHILLER
    TYPE               = LOOP-TO-LOOP-HP
    CHW-LOOP           = "Chilled Water Loop"
    CHW-PUMP           = "Evap HX Pump"
    CW-LOOP            = "Hot Water Loop"
    CW-PUMP            = "Cond HX Pump"
    WELL-LOOP          = "Well Loop"
    WELL-FLOW-CTRL     = VARIABLE-FLOW

    $ Specify the performance and rated conditions
    CAPACITY           = .213    $ millions of Btu
    START-UP-TIME      = .05
    POWER              = 19.08   $ kW
    CHW-HEAD           = 30.
    RATED-CHW-T        = 31.04
    RATED-CHW-FLOW     = 3.27    $ gpm/ton
    CW-HEAD            = 30.0
    RATED-COND-T       = 97.33
    RATED-CW-FLOW      = 4.08

    EVAP-HX-UA         = 48000.
    EVAP-HX-SETPT-T    = 45.
    COND-HX-UA         = 17700.
    COND-HX-SETPT-T    = 75.
    ..
```

HEAT-REJECTION

The program now distinguishes between the conditions at which the component is rated, versus the conditions to which a component is to be designed:

- Rated conditions - If you specify a CAPACITY or ELEC-INPUT-RATIO, that value corresponds to a certain temperature drop through the tower, a given wetbulb temperature, and a given approach to the wetbulb temperature. These are the *rated conditions*. By default, the rated conditions correspond to the Cooling Tower Institute standard conditions (10°F range, 7°F approach, 78°F wetbulb), although this is not a requirement. You may specify a CAPACITY at a different set of rated conditions provided you also define the RATED-RANGE, RATED-APPROACH, and RATED-WETBULB.

  Note that the ELEC-INPUT-RATIO is also assumed to be at these same conditions. Alternatively, you may specify the FAN-KW/CELL in lieu of modifying the electric input ratio.

- Design conditions – If you allow the program to auto-size a cooling tower, the program will size the tower to match the design conditions (loop temperature drop, wetbulb, approach to wetbulb) encountered during the design-sizing run-periods. These design conditions are usually not the same as the rated conditions. Since the default ELEC-INPUT-RATIO is specified at the rating conditions, the program converts the size of the tower at the design conditions to the size of the tower at the rated conditions, and can then calculate the default power consumption.

The default design conditions may not match your intended sizing criteria. For example, based on the DESIGN-COOL-T of the condenser loop and the wetbulb encountered during the peak design-sizing hour, the program may size the tower to a wetbulb of 70°F and an approach of 15°F. If instead you want a wetbulb of 72°F and an approach of 8°F, you may specify these criteria.

CAPACITY
The size of the heat-rejection device. If you do not specify this keyword, the capacity will default to the loop capacity, adjusted by the CAPACITY-RATIO. If no CAPACITY-RATIO is input, then the capacity will default to the loop capacity divided by the number of heat-rejection devices attached to the loop.

If you specify a CAPACITY at other than the Cooling Tower Institute rated conditions (10°F range, 7°F approach, 78°F wetbulb), then you should also specify the RATED-RANGE, RATED-APPROACH, and/or the RATED-WETBULB at which this capacity occurs. Since the ELEC-INPUT-RATIO is also at the rated conditions, you should modify the elec-input-ratio to match the rated conditions, or specify the FAN-KW/CELL instead.

CAPACITY-RATIO
If CAPACITY is not specified, this is the fraction of the design loop capacity that this component will be sized to meet. If you are defining two components of identical size that should just meet the design loop load, then CAPACITY-RATIO should be set to 0.5 for each component. If you want to include a 20% safety factor in each component, then set the CAPACITY-RATIO of each component to 0.6.

If you don't specify CAPACITY or CAPACITY-RATIO, then the capacity will default to the loop capacity divided by the number of heat-rejection devices attached to the loop. When autosizing a tower, the program sizes the the tower to meet the design-sizing load corresponding to the DESIGN-RANGE, DESIGN-APPROACH, and DESIGN-WETBULB, or their design-sizing defaults.

RATED-RANGE
The temperature drop through the tower at which the tower CAPACITY or ELEC-INPUT-RATIO is defined. The default (10°F or 3.9°K) corresponds to the CTI rating point.

RATED-APPROACH
The approach (difference between tower water leaving temperature and wet-bulb) at which the tower CAPACITY or ELEC-INPUT-RATIO is defined.. The default (7F or 3.9K) corresponds to the CTI rating point of 85°F (29.4°C) leaving tower water temperature when the wet-bulb is 78°F (25.6°C).

RATED-WETBULB
The wetbulb temperature at which the tower CAPACITY or ELEC-INPUT-RATIO is defined. The default (78°F or 25.6°C) corresponds to the point at which towers are rated by CTI.

DESIGN-RANGE
When the program auto-sizes the tower, specifies the design temperature drop through the tower. The default is the temperature rise of the tower's condenser loop. Normally you should let this value default unless you want the program to size the tower to a different temperature drop.

DESIGN-APPROACH
When the program auto-sizes the tower, specifies the design approach (difference between tower water leaving temperature and wet-bulb). The default is the difference between the CIRCULATION-LOOP:DESIGN-COOL-T and the design-sizing wetbulb temperature. Normally you should let this value default, unless you want the program to design the tower to a different temperature.

Specifying a higher approach when other conditions are fixed (including design wet-bulb) will cause the program to size a smaller tower (in terms of flow capacity at CTI conditions, not heat rejection capacity). Energy consumption may then either increase or decrease depending on CAPACITY-CTRL and the temperature setpoint.

DESIGN-WETBULB

When the program auto-sizes the tower, specifies the design wetbulb temperature. The default is the design-sizing wetbulb temperature. Normally you should let this value default, unless you want the program to design the tower to a different temperature.

Specifying a lower design wet-bulb when other conditions are fixed (including design approach) will cause the program to size a larger tower (in terms of flow capacity at CTI conditions, not heat rejection capacity). Energy consumption may then either increase or decrease depending on CAPACITY-CTRL and the temperature setpoint.

CAP-FAPP&WB

Takes the U-name of a bi-quadratic curve that adjusts the flow capacity as a function of the approach and wet-bulb. The program calculates the hourly water flow of the tower as

$$Flow = FlowCTI * f(APP,WB) / f(RNG,WB) * f(air\ flow)$$

where FlowCTI is the nominal flow rate at CTI conditions, f(APP,WB) is the curve CAP-FAPP&WB, f(RNG,WB) is the curve CAP-FRNG&WB, and f(air flow) is the curve CAP-FAIRFLOW. Note that you do not specify FlowCTI. The program calculates this value based on CAPACITY and the RATED-WET-BULB, RATED-APPROACH and RATED-RANGE temperatures.

CW-HEAD

The condenser water head loss through the tower at the rated conditions. Includes the effect of piping, spray nozzles, etc. For design purposes, this head is used directly; unlike components such as chillers, this head is not adjusted for the actual design flow vs. flow at rated conditions.

CW-DT

Is the condenser-water temperature rise through the cooling tower corresponding to the CW-HEAD. If specified, then the CW-HEAD will be adjusted to be the head at the actual design flow using this relationship:

$$Head_{des} = CW\text{-}HEAD * (CW\text{-}DT\ /\ dT_{des})^{1.8}$$

where

$Head_{des}$ the tower head at design flow
dT_{des} the tower temperature drop at design flow

If not specified, then the CW-HEAD is assumed to be the head the the actual design-sizing temperature drop, and is not adjusted.

RATED-INLETS-TD
DRY-INLET-DT (old keyword)

When the fluid cooler is running with a dry coil (winter mode), specifies the temperature differential between the entering fluid and the entering air necessary to achieve the rated heat rejection capacity. For the fluid cooler, the rated heat rejection capacity is the assumed to be the capacity the tower has when running wet at the rated conditions, which by default is the CTI conditions.

If the condenser water design setpoint is 85F (29.4C) and the loop has a 10F (5.6K) design temperature rise, then the water entering the cooler at design conditions will be 95F (35C). Since the default dry-coil differential is 70F (38.9K), the air temperature would have to be 25F (-3.9C) for the cooler to achieve its rated capacity.

For a fluid cooler, the default value assumes that the coil consists of bare tubes. If the fluid cooler has an extended surface coil (fins), then the required inlet temperature difference will be less. A reasonable value for a coil with fins on all its rows would be 48F (26.7K). If only a portion of the rows are finned, then the temperature difference should be somewhere between 48F (26.7K) and 70F (38.9K).

DRY-HX
is not longer used for the fluid-cooler or drycooler. Instead, the most relevant heat-exchanger properties are imbedded in the component command.

ELEC-INPUT-RATIO
No longer used for the drycooler (unchanged for all other types); see POWER/AIRFLOW

AIR-TO-FLUID-FLOW
No longer used for the drycooler (unchanged for the fluid-cooler); see AIRFLOW-TD/CAP

AIRFLOW-TD/CAP
is the ratio of airflow to nominal capacity per degree temperature differential for the drycooler's fan(s) expressed as

AIRFLOW-TD/CAP = Airflow * TD / Drycooler capacity

Typically, the capacity of a drycooler is published for a 25°F TD, where the TD is the difference between the entering fluid temperature, and the entering air temperature. For example, if the entering fluid temperature is 120°F and the entering air temperature is 95°F, then the TD is 25°F.

POWER/AIRFLOW
is the ratio of the full-load power of the drycooler fan(s) to the fan airflow at sea level. The program uses this value to determine the default value of the FAN-KW/CELL.

Ratio = (Fan electric power in kW) / (Nominal airflow)

CW-HX
is not longer used for the open-tower with heat-exchanger. Instead, the most relevant heat-exchanger properties are imbedded in the component command.

FAN-OFF-AIRFLOW
For drycoolers, and fluid coolers running in the dry mode, is the ratio of the air flow through the unit when the fans are off (i.e., flow due to natural convection) to the air flow at high speed. This value is used to determine the capacity due to natural convection when the fan is off.

PUMP
HEAD-SETPT-RATIO
This keyword is no longer used.

EQUIP-CTRL
LOADS-THRU-1,5

These keywords are no longer used. They caused problems with users because occasionally the LOADS-THRU-* value specified did not correlate well with the hourly capacity of the equipment in the range. This was particularly true of chillers running at a temperature significantly different than their design temperature, and cooling towers.

Instead, for a given set of equipment (CHILLERS-1, BOILERS-1, etc.), the program calculates the hourly capacity of the equipment in the set, modified by the MAX-LOAD-* listed for the equipment, and compares it to the required load. The program will work through each set until it finds the first one that can handle the load.

WATERSIDE EQUIPMENT IN PARALLEL OR SERIES

Introduction

Previous versions of the plant module modeled two or more boilers, chillers, or cooling towers in a parallel-only configuration. The program now models both parallel, series, and series/parallel configurations. Each configuration has its own advantages and disadvantages, and the best choice varies with the application.

Since series applications are commonly applied to chillers, most of this discussion is in the context of chillers. Boilers, domestic water heaters and hot/chilled-water meters are also supported in series, although that would be unusual.

For hybrid ground-loop heat exchangers with supplemental heating and/or cooling (boilers and/or heat-rejection components), the progam always assumes the equipment is in series, with the ground-loop heat exchanger upstream of the supplemental equipment. Like other loops with equipment in series, inactive equipment may be bypassed using the SERIES-BYPASS keyword.

Parallel Configuration

In a parallel configuration, the return flow enters a header and is divided between the chillers in proportion to their size. The chillers may be the same size, or may be different sizes for improved staging (such as 1/3, 2/3 of design load). Chillers in parallel are best suited for *variable-flow* applications (2-way valves on most loads), where the flow drops off at least as fast as the load. The program supports up to 10 chillers in parallel.

Parallel equipment does *not* work as well in a *constant-flow* loop (3-way valves on coils). This is because a single chiller usually cannot accept the entire flow of the loop; instead a portion of the fluid must be bypassed around the chiller, and the leaving temperature of the chiller must be depressed to make up for the bypassed fluid.

For example consider a 1000 gallon/minute constant-flow chiller plant having two chillers in parallel, each chiller sized for 500 gallons/minute. The chilled-water setpoint is fixed at 44°F all hours. The system is designed for a 10°F temperature rise, so that the design return temperature is 54°F. If the hourly load is 50% of design, only one chiller is needed to satisfy the load, however one chiller may not be sufficient to satisfy the flow. Consider the following scenarios:

1. <u>Full flow through one chiller</u> - To run one chiller at 44°F will require that the chiller accept the entire flow, which is double the chiller's design flow. But doubling the flow through the chiller almost quadruples the chiller's pressure drop, and the high fluid velocity may result in tube erosion and may void the manufacturer's warranty. Or, the pump may not be sized to deliver the required flow at the unexpectely large head. Sizing the pump to overcome the head results in higher pumping energy.

    To allow the hourly flow to be double the design flow, specify CHW-MAX-FLOW = 2.0

2. <u>Bypass flow around chiller</u> - If half of the fluid is bypassed around the chiller (allowed to flow through the inactive chiller), then the chiller's pressure drop does not increase. However, to maintain a leaving setpoint of 44°F, the chiller will have to operate at a temperature lower than 44°F. At 50% load, the return temperature and bypassed flow are 49°F, and the chiller will have to operate at 39°F to compensate. This lower temperature results in a 6% decrease in chiller efficiency.

    To simulate an automatic chiller bypass, specify CHW-MAX-FLOW = 1.0, which is is the default. Note that part-load chiller efficiency can be improved by resetting the supply temperature.

3. <u>Choked flow through one chiller</u> – This alternative attempts to route the entire flow through the one chiller, but the pump is not sized to overcome the excess head, thereby choking the flow. However, a

choked flow does not guarantee that a coil operating at full load receives the necessary flow, and the program does not account for the impact on airhandler performance.

If the program encounters this situation, a warning message will be issued. Results may not be accurate for a system with multiple coils that peak at different times of the day.

Note that, while either scenario #1 or #2 might be reasonable for a plant with two chillers, neither scenario may be realistic for three or more chillers.

You may specify a pump on the evaporator of each chiller. If pumps are also attached to the loop, then the evaporator pump simply circulates fluid through the chiller, and may be controlled in either a constant-flow or variable-flow mode (CHILLER:CHW-FLOW-CTRL). If variable flow, then the pump modulates to match the loop flow allocated to the chiller. If the loop does not have a separate pump, then the chiller pump(s) will also power the loop, and will be either constant-flow or variable-flow as determined by the loop.

By default, the program will stage the chillers in the combination that best matches the load. Alternatively, you may specify an EQUIP-CTRL sequence.

Example of Chillers in Parallel

```
"Parallel Plant" = CIRCULATION-LOOP
   TYPE              = CHW
   EQUIP-CONFIG      = PARALLEL  $ the default
   . . . .

"Chiller 1"          = CHILLER
   TYPE              = ELEC-HERM-CENT
   CHW-LOOP          = "Parallel Plant"
   ..

"Chiller 2"          = CHILLER
   TYPE              = ELEC-HERM-CENT
   CHW-LOOP          = "Parallel Plant"
   ..
```

Series Configuration

When two chillers are in series, one chiller is located upstream of the other, and the chilled water flows through each chiller sequentially. Each chiller is sized for the full flow, but for only a portion of the total load. The chillers may be the same size, or may be different sizes for improved staging (such as 1/3, 2/3 of design load). Chillers in series are preferred for *constant-flow* applications (3-way valves on most loads), and possibly for low-flow/high temperature rise systems.

Most centrifugal chillers are custom built for the application, and the manufacturer usually adjusts the number of passes through the evaporator in accordance with the evaporator's design temperature drop. The program recognizes this practice, and adjusts the default CHW-HEAD and RATED-CHW-FLOW as a function of the CIRCULATION-LOOP:LOOP-DESIGN-DT and if the chiller is in series with another chiller.

Note also that the program simulates chiller evaporators in series, but not chiller condensers. Condensers are always assumed to be in parallel.

Like chillers in parallel, you may specify a pump on the evaporator of each chiller, and control it in a constant-flow or variable-flow mode. These evaporator pumps act only to circulate flow through the evaporator. While parallel-chiller pumps can power the loop, series-chiller pumps can not; the loop must have its own pump.

By default, the program will stage the chillers to best match the the load. Alternatively, you may specify an EQUIP-CTRL sequence. When both chillers are running, the program splits the temperature drop through each based on capacity.

Example of Chillers in Series

```
“Series Plant” = CIRCULATION-LOOP
   TYPE              = CHW
   EQUIP-CONFIG      = SERIES
   DOWNSTREAM-SPLIT  = 0.5
   . . . .

“Chiller 1”          = CHILLER
   TYPE              = ELEC-HERM-CENT
   CHW-LOOP          = “Series Plant”
   CHW-SERIES-LOCN   = DOWNSTREAM
   ..

“Chiller 2”          = CHILLER
   TYPE              = ELEC-HERM-CENT
   CHW-LOOP          = “Series Plant”
   CHW-SERIES-LOCN   = UPSTREAM
   ..
```

Series/Parallel Configuration

The program also supports 4 or more chillers in a series/parallel configuration. For example, a plant may have two chillers upstream of another two chillers. The program assumes a header between the two sets of chillers, so that the upstream chillers are in parallel with each other, as are the downstream chillers. In other words, either upstream chiller can feed into either downstream chiller.

The program supports up to 10 chillers in a series/parallel configuration. While the number of chillers upstream and downstream are usually the same, this is not mandatory.

For load and flow sizing calculations, the CIRCULATION-LOOP:DOWNSTREAM-SPLIT is used to prorate the peak load between the series-downstream and series-upstream equipment. The CHILLER:CAPACITY-RATIOs act on the load in a given location (downstream or upstream), depending on the chiller's location. In other words, the DOWNSTREAM-SPLIT divides the load across equipment in series, and the CAPACITY-RATIOs act across equipment in parallel. An example is shown below.

Like chillers in parallel, you may specify a pump on the evaporator of each chiller, and control it in a constant-flow or variable-flow mode. These evaporator pumps act only to circulate flow through the evaporator. While parallel-chiller pumps can power the loop, series-chiller or series/parallel-chiller pumps cannot; the loop must have its own pump.

Example of Chillers in Series/Parallel

```
“Series/Parallel Plant” = CIRCULATION-LOOP
   TYPE              = CHW
   EQUIP-CONFIG      = SERIES
   DOWNSTREAM-SPLIT  = 0.5
   . . . .
```

```
Downstream-1          = CHILLER
   TYPE               = ELEC-HERM-CENT
   CHW-LOOP           = "Series/Parallel Plant"
   CHW-SERIES-LOCN    = DOWNSTREAM
   ..

Downstream-2          = CHILLER
   TYPE               = ELEC-HERM-CENT
   CHW-LOOP           = "Series/Parallel Plant"
   CHW-SERIES-LOCN    = DOWNSTREAM
   ..

Upstream-1            = CHILLER
   TYPE               = ELEC-HERM-CENT
   CHW-LOOP           = "Series/Parallel Plant"
   CHW-SERIES-LOCN    = UPSTREAM
   ..

Upstream-2            = CHILLER
   TYPE               = ELEC-HERM-CENT
   CHW-LOOP           = "Series/Parallel Plant"
   CHW-SERIES-LOCN    = UPSTREAM
   ..
```

The example above uses 4 chillers, all of the same size. While DOWNSTREAM-SPLIT is mandatory for series configurations, the CHILLER:CAPACITY-RATIO is optional. If not specified, the capacity ratio will default to 1.0 divided by the number of chillers at a given location (downstream or upstream). Since there are two downstream chillers, the capacity ratio defaults to 0.5. The same is true for the upstream chillers. If there were three downstream chillers and two upstream chillers, the capacity ratio for the downstream chillers would default to 0.333, while the capacity ratio for the downstream chillers would default to 0.5.

By default, the program will stage the chillers to best match the the load. Alternatively, you may specify an EQUIP-CTRL sequence. However, regardless of which method is chosen, the program will insist on loading a set of chillers in parallel prior to loading chillers in series. This minimizes the flow that must be bypassed in a constant-flow loop.

For example, consider a 1000 ton 4-chiller plant arranged in a series/parallel configuration. The two downstream chillers are each sized at 300 tons, and the two upstream chillers are each sized at 200 tons. The plant uses the following EQUIP-CTRL sequence:

```
CHILLER-CTRL = EQUIP-CTRL
   TYPE               = COOLING
   CIRCULATION-LOOP   = "The CHW Loop"
   CHILLERS-1         = (Downstream-1, Upstream-2,
                        Upstream-1, Downstream-2)
   ..
```

The program first breaks this sequence down into two sequences; one for the downstream parallel chillers, and one for the upstream parallel chillers. Depending on which set of parallel chillers can best meet the load, the program loads those chillers first, in the order specified by the EQUIP-CTRL. If both the upstream and downstream sets are required, then the program uses both and splits the temperature based on capacity:

Load	Staging
200 tons	Upstream-2 (with bypass if flow requires)
300 tons	Downstream-1 (with bypass if flow requires)
400 tons	Upstream-2, Upstream-1 (no bypass)
500 tons	Downstream-1, Downstream-2 (no bypass)
>600 tons	All chillers, 60% to downstream, 40% to upstream

Building Description Language Changes

CIRCULATION-LOOP

EQUIP-CONFIG

PARALLEL   the default, specifies that equipment is in parallel. Up to 10 units may be specified. A parallel configuration is best used only when the loop is variable flow. Series equipment is recommended for constant-flow loops.

SERIES   specifies that equipment is in series. This configuration is normally used for constant-flow loops, or variable-flow loops with high temperature drops. Parallel equipment is normally preferred for variable-flow loops with moderate temperature drops.

A loop pump is required for the series configuration. For parallel configuration, the loop may have a pump, or the loop may be powered by pumps attached to each equipment unit.

DOWNSTREAM-SPLIT

When EQUIP-CONFIG = SERIES, specifies the fraction of the peak loop load to which the downstream chillers will be sized; with the upstream chillers sized to the remainder. This keyword is used for sizing calculations (both load and flow), and is necessary even if the chiller sizes are explicitly defined; it is a required keyword for the series configuration.

For example, consider the case of two chillers piped in series. If the downstream chiller is to be half the size of the upstream chiller, then the DOWNSTREAM-SPLIT = 0.33. The downstream chiller is then sized to meet 33% of the peak load and the upstream chiller is sized to meet the remainder; or 67% of the peak load (twice the load of the downstream chiller).

The CHILLER:CAPACITY-RATIO can be specified in addition to the DOWNSTREAM-SPLIT. While in the parallel case the CAPACITY-RATIO applies to the total peak load, in the series case the CAPACITY-RATIO applies to the load at either the upstream or downstream location; depending on where the chiller is located. This capability is most useful in series/parallel configurations, where the upstream and/or downstream location has more than one equipment unit, and the units in parallel are of different sizes. It may also be used to oversize a chiller.

For hybrid ground-loop heat pump systems consisting of a ground-loop heat exchanger and a supplemental cooling tower and/or boiler, the supplemental equipment is always located downstream of the ground-loop heat exchanger. In this case, the DOWNSTREAM-SPLIT specifies the fraction of peak heating or cooling load that the supplemental equipment is sized to satisfy. If the GROUND-LOOP-HX:SIZE-FIELD-MULT= YES, then the FIELD-MULTIPLIER will be defaulted based on the remaining portion allocated to the upstream equipment.

SERIES-BYPASS

When EQUIP-CONFIG = SERIES, specifies whether UPSTREAM or DOWNSTREAM equipment can be bypassed when inactive. The most common example would be two chillers in series, but with only one chiller operating. If the inactive chiller can be bypassed, then the pump head will be reduced.

This keyword also applies to a waterside economizer in series with a chiller.

YES	the default, specifies that upstream or downstream equipment can be bypassed when inactive. Pump head will be reduced in this situation
NO	specifies that inactive upstream or downstream equipment cannot be bypassed. Even when the equipment is off, the pump will have to overcome the head of the equipment.

There is a special case for a hybrid WLHP system consisting of a ground-loop heat exchanger and either a cooling tower and/or boiler. In this case, the boiler/tower is always in series downstream of the ground-loop heat exchanger, and is always bypassed when inactive (otherwise the cooling tower could loose significant amounts of heat during winter operation, which is not simulated); SERIES-BYPASS is unused. A separate keyword, GLHX-BYPASS applies to the ground-loop heat exchanger.

GLHX-BYPASS

For a hybrid ground-loop heat exchanger system, specifies whether the ground-loop heat exchanger can be bypassed when it is non-productive (heating when the loop requires cooling, or cooling when the loop requires heating). This differentiation in control allows for the boiler and/or cooling tower to be bypassed, while the ground-loop heat exchanger may always be kept in the loop.

NO	the default, specifies that the ground-loop heat exchanger cannot be bypassed. Even when the ground-loop is non-productive, such as when it is heating when the loop requires cooling, it will remain in the circuit, and the pump will have to overcome the head of the equipment.
YES	specifies that ground-loop heat exchanger can be bypassed when inactive. Pump head will be reduced in this situation

This type of configuration might be useful if the loop's cooling setpoint control. is reset on wetbulb. During times when the wetbulb is low, the tower can drop its temperature supplied to the building, dropping the return temperature. The ground-loop heat exchanger may then discharge surplus heat, which is then immediately disposed of by the tower. This might allow the cooling-mode loop temperature to be lower on average than it would be otherwise.

CHILLER

CHW-SERIES-LOCN

when the CHW-LOOP has an EQUIP-CONFIG = SERIES, is a required entry specifying whether this chiller's evaporator is at the upstream or downstream location. (Chiller condensers are always modeled in parallel.)

DOWNSTREAM	specifies that the chiller is downstream of another chiller. More than one chiller may be at the same location.
UPSTREAM	specifies that the chiller is upstream of another chiller. More than one chiller may be at the same location.

HW-SERIES-LOCN
This keyword applies only to chiller/heaters. When the HW-LOOP has an EQUIP-CONFIG = SERIES, is a required entry specifying whether this chiller' is at the upstream or downstream location.

    DOWNSTREAM   specifies that the chiller is downstream of another chiller or boiler. More than one chiller may be at the same location.

    UPSTREAM   specifies that the chiller is upstream of another chiller or boiler. More than one chiller may be at the same location.

CHW-MAX-FLOW
specifies the maximum flow allowed through the chiller evaporator, expressed as a fraction of the design flow. If the chiller can handle the load, but the associated flow is greather than the chiller can handle, then the excess flow will be bypassed around the chiller. The chiller's leaving temperature will be depressed to compensate for the bypassed flow, thereby maintaining the required loop setpoint.

HW-MAX-FLOW
This keyword applies only to chiller/heaters. It specifies the maximum flow allowed through the chiller heating section, expressed as a fraction of the design flow. If the chiller can handle the load, but the associated flow is greather than the chiller can handle, then the excess flow will be bypassed around the chiller. The chiller's leaving temperature will be raised to compensate for the bypassed flow, thereby maintaining the required loop setpoint.

BOILER
HW-SERIES-LOCN
when the HW-LOOP has an EQUIP-CONFIG = SERIES, is a required entry specifying whether this boiler is at the upstream or downstream location.

    DOWNSTREAM   specifies that the boiler is downstream of another boiler. More than one boiler may be at the same location.

    UPSTREAM   specifies that the boiler is upstream of another boiler. More than one boiler may be at the same location.

HW-MAX-FLOW
specifies the maximum flow allowed through the boiler, expressed as a fraction of the design flow. If the boiler can handle the load, but the associated flow is greather than the boiler can handle, then the excess flow will be bypassed around the boiler. The boiler's leaving temperature will be raised to compensate for the bypassed flow, thereby maintaining the required loop setpoint.

DW-HEATER
DHW-SERIES-LOCN
when the DHW-LOOP has an EQUIP-CONFIG = SERIES, is a required entry specifying whether this heater is at the upstream or downstream location.

    DOWNSTREAM   specifies that the heater is downstream of another heater. More than one heater may be at the same location.

    UPSTREAM   specifies that the heater is upstream of another heater. More than one heater may be at the same location.

DHW-MAX-FLOW

specifies the maximum flow allowed through the heater, expressed as a fraction of the design flow. If the heater can handle the load, but the associated flow is greather than the heater can handle, then the excess flow will be bypassed around the heater. The heater's leaving temperature will be raised to compensate for the bypassed flow, thereby maintaining the required loop setpoint.

HEAT-REJECTION

CW-SERIES-LOCN

This keyword is inactive for heat-rejection devices; towers are always assumed to operate in parallel, except in the case where a tower co-exists with a ground-loop heat exchanger. In this case, the equipment is assumed to be in series, with the ground-loop heat exchanger upstream of the tower.

CW-MAX-FLOW

specifies the maximum flow allowed through the tower, expressed as a fraction of the design flow. If the tower can handle the load, but the associated flow is greather than the tower can handle, then the excess flow will be bypassed around the tower. The tower's leaving temperature setpoint will be raised to compensate for the bypassed flow, thereby maintaining the required loop setpoint.

GROUND-LOOP-HX

LOOP-SERIES-LOCN

While this keyword exists, it is inactive and cannot be modified by the user. If a hybrid system is specified consisting of a ground-loop heat exchanger and supplemental heating and/or cooling (boiler and/or heat-rejection), then the equipment is always assumed to be in series, with the ground-loop heat exchanger upstream of the supplemental equipment.

HX-MAX-FLOW

specifies the maximum flow allowed through the ground loop, expressed as a fraction of the design flow. If the ground loop can handle the load, but the associated flow is greather than the ground loop can handle, then the excess flow will be bypassed around the ground loop. The ground loop's leaving temperature will be calculated based on the non-bypassed flow, and then adjusted to take into account the bypassed flow.

CHW-METER and STEAM-METER

LOOP-SERIES-LOCN

when the CIRCULATION-LOOP has an EQUIP-CONFIG = SERIES, is a required entry specifying whether this meter is at the upstream or downstream location. (This is a very unusual configuration, however the symmetry of the code supports it!)

DOWNSTREAM   specifies that the meter is downstream of a boiler or chiller.

UPSTREAM   specifies that the meter is upstream of a boiler or chiller.

COOLING TOWER WETBULB RESET CONTROL

Introduction

To maximize cooling plant efficiency, it is advantageous to operate a cooling towers at a low setpoint. However, if the setpoint is less than the outdoor wetbulb temperature, then the tower fans will waste energy trying to achieve an impossible setpoint. This feature allows the condenser water temperature setpoint to be reset based on the wetbulb temperature.

The temperature may be reset using either

- A fixed differential

- A variable differential – this recognizes that, for a given load, as the wetbulb drops a tower cannot achieve the same approach to the wetbulb as it can at higher wetbulbs.

Building Description Language Changes

CIRCULATION-LOOP (TYPE = WLHP or CW)

COOL-SETPT-CTRL

Code word specifies the loop temperature control sequence. This is an existing keyword. Only the WETBULB-RESET option is new:

FIXED	specifies that the loop supply temperature is controlled to a fixed value, specified by the COOL-SEPT-T
OA-RESET	specifies that the loop supply temperature is reset on outdoor air according to the COOL-RESET-SCH.
SCHEDULED	specifies that the loop supply temperature is controlled to a schedule specified by the COOL-SETPT-SCH.
LOAD-RESET	specifies that the loop supply temperature is reset so that the valve of the worst-case coil is fully open. The minimum reset temperature is the MIN-RESET-T, and the maximum is the MAX-RESET-T. LOAD-RESET is applicable to any loop serving a chilled-water coil (CHW, PIPE2). It is also applicable to a condenser-water loop; here this control mode will enable the cooling tower temperature to float with the load and wet-bulb temperature as described in the cooling tower sections.
	Since a WLHP loop also uses a cooling tower, LOAD-RESET is applicable to the heat-rejection side of a WLHP loop. It does not apply, however, to the heating setpoint of a WLHP loop.
	This mode maximizes the efficiency of the primary equipment and minimizes the loop's thermal losses (but at the expense of pumping energy in a variable-flow loop). Refer to LOOP-FLOW-RESET for information on how to minimize the pumping penalties associated with this control scheme.
WETBULB-RESET	For CW and WLHP loops only, specifies that the loop temperature cooling setpoint is reset according to the outdoor wetbulb temperature, plus an offset. The

offset may be either fixed, or may vary with the wetbulb. See the keywords COOL-SETPT-T, CW-AMBIENT-DT and WETBULB-RATIO for more information.

COOL-SETPT-T

The cooling setpoint when COOL-SETPT-CTRL = FIXED, the minimum temperature when COOL-SETPT-CTRL = LOAD-RESET, and the target setpoint for COOL-SETPT-CTRL = WETBULB-RESET. The default is the DESIGN-COOL-T, reduced by half the throttling range LOOP-SETPT-RNG.

In previous versions of the program, for a CW loop having COOL-SETPT-CTRL = LOAD-RESET, this value acted as an upper limit on the floating temperature control. This is no longer true. Instead, the program uses the MAX-RESET-T, similar to other loop types.

For COOL-SETPT-CTRL = WETBULB-RESET (applicable only to the cooling setpoint for CW and WLHP loops), specifies the cooling setpoint when the target wetbulb is CW-AMBIENT-DT degrees less than the setpoint. As the hourly wetbulb varies, the setpoint is calculated as

        TargetWB   = COOL-SETPT-T – CW-AMBIENT-DT   (fixed all hours)
        dTsetpt   = CW-AMBIENT-DT + [(TargetWB - HourlyWB) * WETBULB-RATIO]
        Tsetpt   = HourlyWB + dTsetpt

The default for WETBULB-RATIO is 0.28, which recognizes that, as the wetbulb drops, the tower capacity for a given approach to the wetbulb also drops; for a given load, a tower cannot achieve the same approach to wetbulb as it can at higher wetbulbs. To track the wetbulb using a fixed differential, specify WETBULB-RATIO = 0.

CW-AMBIENT-DT

For COOL-SETPT-CTRL = WETBULB-RESET (applicable only to the cooling setpoint for CW and WLHP loops), specifies the differential between the hourly cooling setpoint and the wetbulb.

As the hourly wetbulb varies, the setpoint is calculated as

        TargetWB   = COOL-SETPT-T – CW-AMBIENT-DT   (fixed all hours)
        dTsetpt   = CW-AMBIENT-DT + [(TargetWB - HourlyWB) * WETBULB-RATIO]
        Tsetpt   = HourlyWB + dTsetpt

The default for WETBULB-RATIO is 0.28, which recognizes that, as the wetbulb drops, the tower capacity for a given approach to the wetbulb also drops; for a given load, a tower cannot achieve the same approach to wetbulb as it can at higher wetbulbs. To track the wetbulb using a fixed differential, specify WETBULB-RATIO = 0.

WETBULB-RATIO

For COOL-SETPT-CTRL = WETBULB-RESET (applicable only to the cooling setpoint for CW and WLHP loops), specifies the differential between the hourly cooling setpoint and the wetbulb.

As the hourly wetbulb varies, the setpoint is calculated as

        TargetWB   = COOL-SETPT-T – CW-AMBIENT-DT   (fixed all hours)
        dTsetpt   = CW-AMBIENT-DT + [(TargetWB - HourlyWB) * WETBULB-RATIO]
        Tsetpt   = HourlyWB + dTsetpt

The default for WETBULB-RATIO is 0.28, which recognizes that, as the wetbulb drops, the tower capacity for a given approach to the wetbulb also drops; for a given load, a tower cannot achieve the same approach to wetbulb as it can at higher wetbulbs. To track the wetbulb using a fixed differential, specify WETBULB-RATIO = 0.

ECONOMIZER MINIMUM DEWPOINT CONTROL

Introduction

When economizers are used together with humidifiers in very cold or dry climates, the energy savings achieved by using an economizer may be more than offset by the energy consumed in re-humidifying very dry air. This feature provides a dewpoint low-limit override to the mixed air controller. The outside air dampers are forced to their minimum position whenever the outdoor dewpoint is below this value.

Building Description Language Changes

CIRCULATION-LOOP (TYPE = WLHP or CW)

ECONO-MIN-DEWPT

for all economizer types, specifies a minimum outdoor-air humidity ratio below which the outside air dampers return to their minimum position. If not specified, there is no minimum allowable dewpoint temperature.

This feature can prevent excessively low humidity levels in buildings located in very cold or dry climates, and may be especially useful when humidifiers are used. Oftentimes, the energy saved by using an economizer may be more than offset by the energy consumed in re-humidifying very dry air.

ZONAL EXTRACTION TEMPERATURE DIFFERENTIALS

Introduction

When sizing a the airflow of a zone terminal, the required zone extraction rate and the differential between the hourly zone temperature and the air handler's MAX-SUPPLY-T, MIN-SUPPLY-T, REHEAT-DELTA-T or other temperatures. The calculated differential may be explicitly overridden uses the keywords described in this section.

Building Description Language Changes

SYSTEM (most types)

HEAT-SUP/RET-DT

Specifies the design differential between the zonal supply and return temperatures for zone airflow sizing calculations when a zone is in the heating mode. When specified, this keyword takes precedence over the MAX-SUPPLY-T, REHEAT-DELTA-T, hourly zone temperature, or other combinations of values; the zonal heating airflow is a function of this differential and the extraction load.

This keyword has an identical keyword within the ZONE command. The default of the zonal keyword is the value specified at the SYSTEM level. At the zone level, this keyword overrides other temperatures, but does not override any user-defined airflows.

COOL-SUP/RET-DT

Specifies the design differential between the zonal supply and return temperatures for zone airflow sizing calculations when a zone is in the cooling mode. When specified, this keyword takes precedence over the MIN-SUPPLY-T, hourly zone temperature, or other combinations of values; the zonal heating airflow is a function of this differential and the extraction load.

This keyword has an identical keyword within the ZONE command. The default of the zonal keyword is the value specified at the SYSTEM level. At the zone level, this keyword overrides other temperatures, but does not override any user-defined airflows.

ZONE (TYPE = CONDITIONED)

HEAT-SUP/RET-DT

Specifies the design differential between the zonal supply and return temperatures for zone airflow sizing calculations when a zone is in the heating mode. When specified, this keyword takes precedence over the MAX-SUPPLY-T, REHEAT-DELTA-T, hourly zone temperature, or other combinations of values; the zonal heating airflow is a function of this differential and the extraction load.

This keyword overrides other temperatures, but does not override any user-defined airflows; such as ASSIGNED-FLOW. The default for this keyword is the same keyword at the SYSTEM level.

For dual duct terminals, this keyword applies to the flow calculated for the hot duct only; airflow from the cold duct due to ventilation or leakage is in addition to the hot duct flow.

Similarly, for fan powered terminals, this keyword applies to the induced airflow only; airflow from the cold duct due to ventilation or leakage is in addition to the induced airflow.

COOL-SUP/RET-DT

Specifies the design differential between the zonal supply and return temperatures for zone airflow sizing calculations when a zone is in the cooling mode. When specified, this keyword takes precedence over the MIN-

SUPPLY-T, hourly zone temperature, or other combinations of values; the zonal cooling airflow is a function of this differential and the extraction load.

This keyword overrides other temperatures, but does not override any user-defined airflows; such as ASSIGNED-FLOW. The default for this keyword is the same keyword at the SYSTEM level.

For dual duct terminals, this keyword applies to the flow calculated for the cold duct only; airflow from the jpt duct due to leakage is in addition to the cold duct flow.

Similarly, for fan powered terminals, this keyword applies to the duct airflow only; airflow induced by the fan is in addition to the duct airflow.

SPACE EQUIPMENT LOADS TO RETURN AIR

Introduction

The ability to specify the fraction of lighting energy that flows directly to the return air has been a long-standing capability of the program. Now, a keyword is provided to allow the specification of the fraction of the space equipment load that flows directly to the return air.

This keyword was specifically implemented to allow hot/cold aisles to be simulated for data centers. However, there are numerous other applications where a fraction of the equipment heat gain may be captured directly by the return air flow; thereby not affecting the space temperature.

In addition to allowing equipment heat to flow directly to the return air, this enhancement also allows the thermostat to be located in either the zone, or in the zone return airflow.

Building Description Language Changes

SPACE (conditioned)

EQUIP-TO-RETURN

Takes a list of values, for up to five equipment types, of the fraction of equipment heat that goes directly to the return air stream. Unless the zone is configured so that return air passes through the equipment (such as in many data center configurations), EQUIP-TO-RETURN should be allowed to default to zero.

This fraction applies to both the sensible and latent equipment heat gains. For example, if EQUIPMENT-KW = 1.0, EQUIP-SENSIBLE = 0.70, EQUIP-LATENT = 0.30, and EQUIP-TO-RETURN = 0.2, then 1.0 * 0.70 * 0.20 = 0.14 kW will flow to the return as sensible heat, and 1.0 * 0.30 * 0.20 = 0.06 kW will flow to the return as latent heat.

Note that, unlike LIGHT-TO-RETURN, there is no "equip-to-space" or "equip-to-other". All equipment heat that is not captured in the return airflow is assumed to go to the space.

ZONE (conditioned)

THERMOSTAT-LOCN

For conditioned zones, specifies the location of the zone's thermostat:

WITHIN-ZONE	the default, specifies that the thermostat is located within the zone.
ZONE-RETURN	specifies that the thermostat is located in the zone's return airflow. While unusual for most systems, this location may be used for air handlers serving data centers.

Unless the zone has heat gains that go directly into the return air (SPACE:LIGHT-TO-RETURN, SPACE:EQUIP-TO-RETURN, ZONE:PLUME-***, ZONE:DIFFUSER-LOSS-***), the zone return air temperature will be the same as the zone temperature (fully mixed airflow), and this keyword is irrelevant. But if the zone has heat gains/losses that are captured by the return airflow, then the return air temperature may be either greater or lesser than the zone temperature. The zone heating and cooling thermostat schedules should reflect the location of the thermostat. The same is also true for the DESIGN-HEAT-T and DESIGN-COOL-T.

When the thermostat is located in the zone return, the fan must run continuously during occupied hours (SYSTEM:INDOOR-FAN-MODE = CONTINUOUS); otherwise the return air temperature cannot be sensed. The program will issue an error if the indoor fan is allowed to cycle.

RESIDENTIAL VARIABLE-REFRIGERANT FLOW SYSTEM

Introduction

This feature allows a residential variable-refrigerant flow (VRF) system to be modeled. The system consists of an outdoor unit featuring a variable-speed compressor that provides cooling or heat-pump heating, and one or more indoor units. Each indoor unit has its own thermostat. The outdoor unit operates whenever any of the indoor units runs, and cycles on/off according to the fraction of the hour the indoor units run. When indoor units are cycling, a statistical calculation is performed to calculate the diversity of indoor unit cycling and the result on the outdoor unit.

A residential VRF system can provide heating or cooling in a given hour, but not both. It does not provide simultaneous heating and cooling. The heating/cooling operating mode can be determined based on a single zone thermostat, or all of the indoor units can be allowed to "vote", with the maximum of the aggregate heating or cooling load determining which mode the indoor units run.

This capability is incorporated only into the PVVT system type.

Building Description Language Changes

SYSTEM
COOL-SOURCE
For certain system types, takes a code-word that specifies the cooling source for the SYSTEM's main cooling coil. Not all system types that accept this keyword allow all cooling sources. Allowed values of COOL-SOURCE are:

ELEC-DX	(The default for PVVT) The system uses an electric direct-expansion compressor. Both air-cooled and water-cooled CONDENSER-TYPEs are supported. When using this option, you specify the DX performance in a manner identical to packaged-VAV or packaged single-zone systems; using the COOLING-EIR, etc. Note: Not all systems allow this choice.
CONDENSING-UNIT	The system uses an outdoor condensing unit serving one or more direct-expansion cooling coils. The coil attaches to the condensing unit via the CONDENSING-UNIT keyword. Applicable only to the PVVT system type.

Condensing-Unit Coils

The following keywords specify the characteristics of a cooling coil attached to a condensing unit (COOL-SOURCE = CONDENSING-UNIT). Like other types of cooling coils, the COOLING-CAPACITY is defined at the RATED-EDB and RATED-EWB. The rated suction temperature is assumed to be the CONDENSING-UNIT:DESIGN-COIL-SST. The rated airflow is the corresponding airflow entered by the user; if not specified then the rated flow is based on the AIRFLOW/CAPACITY for central AHU and zonal coils.

CONDENSING-UNIT
Takes the U-name of a CONDENSING-UNIT to which the cooling coil(s) in this system are connected. This keyword also acts as the default for the keyword of the same name in the ZONE command.

HEAT/COOL-CONFIG
for a system having both heating and cooling coils attached to a condensing-unit, specifies whether separate heating and cooling coils exist, or if a single coil is used in both modes.

COMMON	the default, specifies that a single coil is used for both heating and cooling. If the capacity is not specified, the coil will be sized to the larger of the heating or cooling requirement; typically cooling.

SEPARATE   specifies that the heating and cooling coils are separate. Each coil will be sized independently.

RFG-COIL-CTRL

specifies how the coil is controlled in response to the zone thermostat or discharge air controller:

CYCLE-ON/OFF   the default, specifies that the coil cycles on/off to maintain the average supply temperature. This method will extract more latent energy than a modulating controller.

MODULATE   specifies that the coil modulates the suction temperature to maintain the average supply temperature.

ZONE

TERMINALS/ZONE

For a zone served by a CONDENSING-UNIT, specifies the number of indoor-units that are in the zone. This entry is important only when indoor-units cycle on/off rather than modulate. This value is used to calculate the impact on the outdoor unit of the diversity of operation of the indoor-units,

For example if an outdoor unit serves a single zone, the zone has 3 indoor-units, and the hourly load is 40% of maximum (each indoor unit runs 40% of the hour, but not necessarily simultaneously), the condensing unit will calculate the diversity of indoor-unit operation to be 78%. The outdoor-unit will then run 0.78 of the hour, at a part load ratio of 0.40/0.78 = 0.51.

This keyword only applies to the diversity calculation for a zone served by a CONDENSING-UNIT. Terminal airflow, capacity, etc. should be specified assuming there is only one terminal per zone.

CONDENSING-UNIT

This is a new command that defines all of the operating parameters of an outdoor condensing unit, to which one or more indoor units attach. A U-name must be specified for each condensing unit. This U-name will be referenced by indoor units that are served by this outdoor unit, and will also be used in the heading of the condensing unit report to identify the chiller.

Currently, the condensing-unit is configured in a variable-refrigerant flow (VRF) configuration. For these units, manufacturers typically rate the performance of the equipment as a composite of the indoor and outdoor units. For example, for cooling, the performance is specified as a function of the weighted entering-wetbulb of the indoor units, and the outdoor drybulb. For heating, performance is specified as a function of the weighted entering-drybulb temperature of the indoor units, and the outdoor wetbulb. This program does not follow this convention exactly, as it simulates indoor and outdoor units separately, and recognizes that various indoor units may be operating at significantly different entering air temperatures. For this reason, indoor units are defined relative to the air entering coil temperature, and either the refrigerant suction (for cooling) or condensing (for heating) temperature. The outdoor unit is specified relative to the refrigerant suction or condensing temperature, and the outdoor drybulb or wetbulb.

This approach allows both indoor and outdoor units to be simulated more precisely, and also allows for more energy-efficient control sequences to be implemented in the future. For example, suction/condensing pressure reset can potentially yield significant energy savings during periods of reduced demand. While manufacturers do not incorporate this strategy into the units available at the time of this writing, the algorithms implemented allow for this type of reset to be implemented in the future.

TYPE

Takes a code-word that specifies the configuration of the condensing unit:

COOLING	*future*
HEAT-PUMP	*future*
VRF-COOLING	*future*
VRF-HEAT-PUMP	A variable-refrigerant flow heat pump. In a given hour, this unit may operate in either the heating or cooling mode, but not both. To simulate a unit that simultaneously delivers heating and cooling, use VRF-HEAT-RECOVERY (future).
	For a condensing-unit serving a single indoor unit, heating/cooling operation is determined by the demand of that coil. For an outdoor unit serving more than one indoor unit, heating/cooling operation most commonly is determined by a single indoor unit designated as the master zone (the CONDENSING-UNIT:CONTROL-ZONE). Alternatively, all indoor units may be polled, and the heating/cooling load determined on the basis of whether heating or cooling dominates. The unit will operate in that mode for the hour, ignoring the less-dominant need.
VRF-HEAT-RECOVERY	*future*

RATED-SST

The saturated-suction temperature at which the cooling-mode capacity and power are specified.

Note that, while the cooling-mode capacity and power curves reference the saturated-suction temperature, the default curves ignore this parameter. This is because manufacturers do not publish performance data based on this value.

COOL-RATED-ODB

The outdoor-drybulb temperature at which the cooling-mode capacity and power are specified, either ARI or other.

COOL-MIN-ODB

The minimum outdoor drybulb below which the cooling-mode capacity and power are assumed to be constant. The program assumes that the outdoor fan will modulate below this temperature to maintain the condensing temperature at a setpoint.

COOLING-CAPACITY

The cooling capacity of the condensing-unit (English: millions of Btu, Metric: kW). The specified capacity corresponds to the rated conditions, i.e. the RATED-SST and the COOL-RATED-ODB.

If you do not specify COOLING-CAPACITY, the capacity defaults to the design-sizing indoor unit load.

COOLING-TONS

For English units only, specifies the cooling capacity in tons. This is an alternative to COOLING-CAPACITY, and gives identical results. For a 10-ton condensing-unit, you may specify either COOLING-TONS = 10 or CAPACITY = 0.120 (millions of Btuh)

COOL-CAP-RATIO
When the capacity is not user-defined, specifies the cooling-mode sizing ratio for the condensing unit. To oversize the unit by a factor of 20%, specify 1.2. Note that this factor is in addition to any oversizing specified for the indoor units.

COOL-CAP-FSST&OD
Takes the U-name of a curve that adjusts the cooling capacity of the condensing-unit as a function of the saturated-suction temperature and the outdoor-drybulb temperature. This curve is usually normalized to 1.0 at the rated conditions (RATED-SST, COOL-RATED-ODB), although this is not mandatory (the program will normalize this curve internally).

Note that, because manufacturers did not publish capacity as a funtion of suction temperature at the time of this implementation (2009), the bi-quadratic default curve contains coefficients only for outdoor-drybulb temperature.

MIN-UNLOAD-RATIO
The point, expressed as a part load ratio (PLR), at which compressor unloading stops and hot gas bypass or cycling begins. The heating/cooling *-EIR-FPLR applies in the range of PLR between MIN-UNLOAD-RATIO and 1.0. See MIN-HGB-RATIO.

MIN-HGB-RATIO
The part load ratio where hot gas bypass ends and the compressor starts a cycling mode. MIN-HGB-RATIO is always equal to or less than MIN-UNLOAD-RATIO.

For example, if MIN-UNLOAD-RATIO = 0.25, and MIN-HGB-RATIO = 0.10, then the compressor unloads using the *-EIR-FPLR curve between part load ratios of 1.0 and 0.25, uses hot gas bypass between 0.25 and 0.10 (constant compressor power calculated using PLR = 0.25), and cycles below 0.10 (when running, power is at PLR - 0.25; but adjusted for cycling losses).

COOLING-POWER
An alternative to COOLING-EIR, is the cooling-mode power consumption of the condensing unit (compressor plus outdoor fan) at the rated conditions. When using COOLING-POWER, you must also specify the COOLING-CAPACITY (or COOLING-TONS). The program will calculate the COOLING-EIR as a function of these two values.

COOLING-EER
An alternative to COOLING-EIR, is the ratio of the rated capacity of the condensing unit (Btu) divided by the rated power consumption in Watts (English units only; not valid for metric input). The program will translate this value into the COOLING-EIR.

COOLING-EIR
The electric input ratio (EIR) is the ratio of electric input power to cooling capacity (i.e., the inverse of the cooling coefficient of performance (COP)). The EIR is dimensionless, so the same units for input and capacity should be used. The EIR must correspond to the rated conditions, i.e. the RATED-SST and COOL-RATED-ODB. If you change any of the rated conditions, then you should also specify the EIR at the new conditions.

This keyword is the value that the program uses in all hourly calculations. As an alternative, you may enter either the COOLING-POWER (together with capacity) or COOLING-EER. The program will translate any of these alternative inputs into the COOLING-EIR.

COOL-EIR-FSST&ODB
Takes the U-name of a curve that adjusts the cooling capacity of the condensing-unit as a function of the saturated-suction temperature and the outdoor-drybulb temperature This curve is usually normalized to 1.0 at the rated

conditions (RATED-SST, COOL-RATED-ODB), although this is not mandatory (the program will normalize this curve internally).

Note that, because manufacturers did not publish power as a funtion of suction temperature at the time of this implementation (2009), the bi-quadratic default curve contains coefficients only for outdoor-drybulb temperature.

COOL-EIR-FPLR
Takes the U-name of a curve that adjusts the electric input ratio as a function of

- The part load ratio (PLR) – The PLR is defined as the ratio of the hourly load to the hourly capacity; Load / Cap_{hour}

- The temperature differential between the outdoor drybulb and the saturated-suction temperature.

    The dT term is included for consistency with chillers. For most condensing units, the dT has a negligible effect on part-load performance and can be ignored.

COOL-CLOSS-FPLR
Takes the U-name of a quadratic curve that gives the ratio of the effective compressor output when cycling at minimum speed to the non-cycling output at minimum speed, as a function of the cycling part load ratio. The cycling part load ratio is defined as the cooling load divided by the cooling capacity at minimum output. The curve is used only when the unit is cycling; that is, whenever the cooling load is less than the cooling capacity at minimum output. It expresses the extra run time needed to make up for cycling losses. The curve is normalized to 1.0 at minimum output (cycling part load ratio = 1.0).

COOL-CLOSS-MIN
Is the minimum cycling part load ratio used as input to COOL-CLOSS-FPLR

DESIGN-COIL-SST
The saturated-suction temperature at the fan coil units; used for design sizing of the coils. By default, this temperature is the RATED-SST, but increased by a few degrees to take into account the rise in suction temperature due to piping friction and elevation.

SST-CTRL
Accepts a code-word specifying the control sequence used to control the cooling-mode suction temperature.

Currently, only FIXED is a valid input, as manufacturers do not reset suction temperature to save energy, and performance data as a function of suction temperature is not published.

FLOAT	*future*
FIXED	The suction temperature setpoint is fixed all hours
SCHEDULED	*future*
OA-RESET	*future*
LOAD-RESET	future

SST-SETPT
When SST-CTRL = FIXED, specifies the suction temperature setpoint. The default is the RATED-SST.

SST-SETPT-SCH
future

SST-RESET-SCH
future

MIN-SST-SETPT
future

MAX-SST-SETPT
future

REFG-FLOW-DT
The rise in suction temperature between the condensing-unit and the indoor units due to friction, at full load. The program will adjust this value hourly for actual load.

REFG-HEIGHT-DT
The rise in suction temperature between the condening-unit and the indoor units due to a change in elevation. This value is assumed constant all hours.

RATED-SCT
The saturated-condensing temperature at which the heating-mode capacity and power are specified.

Note that, while the heating-mode capacity and power curves reference the saturated-condensing temperature, the default curves ignore this parameter. This is because manufacturers do not publish performance data based on this value.

HEAT-RATED-OWB
The outdoor-wetbulb temperature at which the heating-mode capacity and power are specified, either ARI or other.

HEAT-MAX-OWB
The maximum outdoor wetbulb above which the heating-mode capacity and power are assumed to be constant. The program assumes that the outdoor fan will modulate above this temperature to maintain the suction temperature at a setpoint.

HEATING-CAPACITY
The heating capacity of the condensing-unit (English: millions of Btu, Metric: kW). The specified capacity corresponds to the rated conditions, i.e. the RATED-SCT and the HEAT-RATED-OWB.

HEAT-CAP-RATIO
When the capacity is not user-defined, specifies the heating-mode sizing ratio for the condensing unit. To oversize the unit by a factor of 20%, specify 1.2. Note that this factor is in addition to any oversizing specified for the indoor units.

HEAT/COOL-CAP
Is the ratio of the heating capacity to the cooling capacity at the rated conditions.

The condensing-unit's COOLING-CAPACITY is the cooling capacity at the rated temperature conditions. At the ARI standard rated conditions, the heating capacity is usually close to the cooling capacity. If however, the heating capacity was only 80% of the cooling capacity, then this keyword would have a value of 0.8

HEAT-CAP-FCT&OWB

Takes the U-name of a curve that adjusts the heating capacity of the condensing-unit as a function of the saturated-condensing temperature and the outdoor-wetbulb temperature. This curve is usually normalized to 1.0 at the rated conditions (RATED-SCT, HEAT-RATED-OWB), although this is not mandatory (the program will normalize this curve internally).

Note that, because manufacturers did not publish capacity as a funtion of discharge temperature at the time of this implementation (2009), the bi-quadratic default curve contains coefficients only for outdoor-wetbulb temperature.

DEFROST-CAP-FOWB

Takes the U-name of a curve that adjusts the heating capacity of the condensing-unit for defrost as a function of the outdoor-wetbulb temperature. This curve must be normalized to 1.0 at maximum outdoor wetbulb at which defrost starts.

HEATING-POWER

An alternative to HEATING-EIR, is the heating-mode power consumption of the condensing unit (compressor plus outdoor fan) at the rated conditions. When using HEATING-POWER, you must also specify the HEATING-CAPACITY. The program will calculate the HEATING-EIR as a function of these two values.

HEATING-EER

An alternative to HEATING-EIR, is the ratio of the rated capacity of the condensing unit (Btu) divided by the rated power consumption in Watts (English units only; not valid for metric input). The program will translate this value into the HEATING-EIR.

HEATING-EIR

The electric input ratio (EIR) is the ratio of electric input power to heating capacity (i.e., the inverse of the heating coefficient of performance (COP)). The EIR is dimensionless, so the same units for input and capacity should be used. The EIR must correspond to the rated conditions, i.e. the RATED-SCT and HEAT-RATED-OWB. If you change any of the rated conditions, then you should also specify the EIR at the new conditions.

This keyword is the value that the program uses in all hourly calculations. As an alternative, you may enter either the HEATING-POWER (together with capacity) or HEATING-EER. The program will translate any of these alternative inputs into the HEATING-EIR.

HEAT-EIR-FCT&OWB

Takes the U-name of a curve that adjusts the heating capacity of the condensing-unit as a function of the saturated-condensing temperature and the outdoor-wetbulb temperature This curve is usually normalized to 1.0 at the rated conditions (RATED-SCT, HEAT-RATED-OWB), although this is not mandatory (the program will normalize this curve internally).

Note that, because manufacturers did not publish power as a funtion of condensing temperature at the time of this implementation (2009), the bi-quadratic default curve contains coefficients only for outdoor-wetbulb temperature

HEAT-EIR-FPLR

Takes the U-name of a curve that adjusts the electric input ratio as a function of

- The part load ratio (PLR) – The PLR is defined as the ratio of the hourly load to the hourly capacity; Load / Cap_{hour}

- The temperature differential between the saturated-condensing and outdoor-wetbulb temperatures

The dT term is included for consistency with chillers. For most condensing units, the dT has a negligible effect on part-load performance and can be ignored.

HEAT-CLOSS-FPLR

Takes the U-name of a quadratic curve that gives the ratio of the effective compressor output when cycling at minimum speed to the non-cycling output at minimum speed, as a function of the cycling part load ratio. The cycling part load ratio is defined as the heating load divided by the heating capacity at minimum output. The curve is used only when the unit is cycling; that is, whenever the heating load is less than the heating capacity at minimum output. It expresses the extra run time needed to make up for cycling losses. The curve is normalized to 1.0 at minimum output (cycling part load ratio = 1.0).

HEAT-CLOSS-MIN

Is the minimum cycling part load ratio used as input to HEAT-CLOSS-FPLR

MAX-COOLING-CAP

The maximum cooling output of the unit, expressed as a multiplier on the COOLING-CAPACITY (for example, 1.06).

When overloaded, power consumption will be calculated based on the full-load power, linearly adjusted as a function of this keyword and the COOLING-MAX-PWR. If the cooling demand of the indoor units rises above this value, then the suction temperature will float upwards, reducing the demand of the indoor-units until the balance point is achieved between indoor-unit demand and the outdoor-unit capacity.

MAX-COOLING-PWR

The maximum cooling-mode power consumption of the unit, expressed as a multiplier on the full load power (for example, 1.02).

When overloaded, power consumption will be calculated based on the full-load power, linearly adjusted as a function of this keyword and the COOLING-MAX-LOAD. If the cooling demand of the indoor units rises above nominal, then the suction temperature will float upwards, reducing the demand of the indoor-units until the balance point is achieved between indoor-unit demand and the outdoor-unit capacity

MAX-HEATING-CAP

The maximum heating output of the unit, expressed as a multiplier on the HEATING-CAPACITY (for example, 1.03).

When overloaded, power consumption will be calculated based on the full-load power, linearly adjusted as a function of this keyword and the HEATING-MAX-PWR. If the heating demand of the indoor units rises above this value, then the condensing temperature will float downward, reducing the demand of the indoor-units until the balance point is achieved between indoor-unit demand and the outdoor-unit capacity.

MAX-HEATING-PWR

The maximum heating-mode power consumption of the unit, expressed as a multiplier on the full load power (for example, 1.02).

When overloaded, power consumption will be calculated based on the full-load power, linearly adjusted as a function of this keyword and the HEATING-MAX-LOAD. If the heating demand of the indoor units rises above nominal, then the discharge temperature will float downward, reducing the demand of the indoor-units until the balance point is achieved between indoor-unit demand and the outdoor unit capacity

DESIGN-COIL-SCT
The saturated-condensing temperature at the fan coil units; used for design sizing of the coils. By default, this temperature is the RATED-SCT, but decreased by a few degrees to take into account the drop in condensing temperature due to piping friction and elevation.

SCT-CTRL
Accepts a code-word specifying the control sequence used to control the heating-mode condensing temperature.

Currently, only FIXED is a valid input, as manufacturers do not reset condensing temperature to save energy, and performance data as a function of condensing temperature is not published.

FLOAT	*future*
FIXED	The suction temperature setpoint is fixed all hours
SCHEDULED	*future*
OA-RESET	*future*
LOAD-RESET	future

SCT-SETPT
When SCT-CTRL = FIXED, specifies the condensing temperature setpoint. The default is the RATED-SCT.

SCT-SETPT-SCH
future

SCT-RESET-SCH
future

MAX-SCT-SETPT
future

MIN-SCT-SETPT
future

CRANKCASE-HEAT
An alternative to CRANKCASE-EIR, is the electric power (Watts) used to heat the crankcase of the compressor(s). The crankcase heater is assumed to modulate as determined by the CRANK-EIR-FPLR curve. Crankcase electric power is allocated to the AUX-ELEC-METER.

CRANKCASE-EIR
Specifies crankcase heater power as the ratio of crankcase power to cooling capacity. This ratio is dimensionless, so the same units for input and capacity should be used. The EIR must correspond to the rated conditions, i.e. the RATED-SST and COOL-RATED-ODB. If you change any of the rated conditions, then you should also specify the EIR at the new conditions.

CRANK-EIR-FPLR
Takes the U-name of a curve that adjusts the electric input ratio as a function of the part-load ratio.

CRANKCASE-MAX-T
The outside temperature above which the crankcase heater is always off.

CONTROL-ZONE

For the HEAT-PUMP condening-unit, specifies the U-name of the zone that determines whether the outdoor-unit is enabled to operate in the heating mode or cooling mode. All fan coils must then run in this mode. If the control zone does not have a heating or cooling demand in a given hour, then the outdoor unit will be enabled to operate in the last mode used by the control zone.

If not specified, then all indoor-units are polled, and the outdoor-unit will run according to the larger of the heating or cooling demand.

AUX-POWER

Accepts a numeric value specifying an auxiliary electrical consumption, such as for controls.

AUX-MODE

Accepts a code-word specifying when the AUX-KW is consumed.

ALWAYS	(default) indicates that the auxiliary power is consumed all hours.
WHEN-ON	indicates that auxiliary power is consumed only during the hours, or fraction of an hour, the unit is operating.
WHEN-OFF	indicates that auxiliary power is consumed only during the hours, or fraction of an hour, the component is off.
SCHEDULED	indicates that the power consumption is scheduled.

AUX-SCHEDULE

When AUX-MODE = SCHEDULED, accepts a U-name of a schedule (TYPE = FRACTION or MULTIPLIER) that varies the AUX-POWER on an hourly basis.

AUX-METER

Accepts the U-name of a meter that supplies the auxiliary energy. This keyword defaults to the MASTER-METER:AUX-ELEC-METER.

ELEC-METER
ELEC-METER

Takes the U-name of the ELEC-METER to which the electricity consumption of the chiller is assigned. The default is the MASTER-METER: COOL-ELEC-METER.

COST-DATA

Takes the U-name of a MATERIALS-COST command, which allows you to define first costs, maintenance costs, etc. for this component.

EQUIPMENT-REPORTS

Takes the code-words YES or NO. When report PS-H of the PLANT-REPORTS is enabled, a report will print for the component unless this keyword is set to NO.

PS-H Loads and Energy Usage for <condensing-unit name>

This report summarizes the performance of an outdoor condensing unit, most commonly associated with a variable-refrigerant flow system. For the component, this report summarizes relevant design information as well as monthly and yearly performance. This report is an expansion of the information provided in PV-A and PS-C; most of the information will be identical with the exception of the monthly performance. For this report to print, PS-H must be specified in PLANT-REPORTS, and the component's EQUIPMENT-REPORTS = YES.

This example illustrates a user-defined cooling and heating capacity that is undersized for the design loads.

The first set of data is design information:

EQUIPMENT TYPE
specifies the type of equipment which is identical to the TYPE code-word originally specified by the user.

FUNCTION
entries may be for cooling only, or for cooling/heating (heat pump). Cooling/heating data is listed on separate lines.

RATED CONDITIONS
Entries are for (cooling on first line, heating on second)

> the cooling/heating capacity at rated conditions (in this example user-defined),
>
> power at rated conditions,
>
> the rated suction or discharge temperature,
>
> the rated outdoor temperature (outdoor wetbulb for heat pump in heating mode),
>
> the electric input ratio,
>
> the crankcase heater power.

DESIGN CONDITIONS
Entries are for

> The peak design-sizing cooling load or heating load. This value is independent of the actual capacity specified.
>
> The cooling/heating capacity at the peak design conditions. If the capacity is defaulted, the capacity will be the peak design-sizing load, adjusted by the sizing ratio. For a heat pump, the defaulted capacity will be based on either the peak heating or cooling load, whichever requires the largest unit. If capacity is user-specified, the capacity is translated from the rated conditions to the peak design conditions.
>
> The power at the design conditions. This is compressor power only; auxiliary and crankcase heat is not included.
>
> The suction or discharge temperature at the peak conditions
>
> The outdoor ambient temperature at the peak conditions. For an air-cooled heat-pump, the temperature is the outdoor wetbulb.

Following the design data is the monthly and yearly performance summary:

COOL LOAD
is the cooling load on the unit.

HEAT LOAD
is the heating load on the unit.

ELEC USE
is the total electrical use of the unit, including compressor, auxiliary and crankcase; excluding indoor units.

AUX ENERGY
is the auxiliary and crankcase power.

For each month and for the year, information is presented on the category total, peak monthly or yearly value, and the time when the peak occurred. Bin information is presented in terms of the number of hours the cooling load, heating load, and power fell into the appropriate part load bin. The part load bin is calculated in terms of the hourly value divided by the design value.

The number of hours the unit was overloaded is reported at the bottom of the report.

```
REPORT- PS-H Loads and Energy Usage for     VRF-Cond                                    WEATHER FILE- CZ12RV2 WYEC2
-----------------------------------------------------------------------------------------------------------------------

                        ---------------- RATED CONDITIONS ----------------   ------------- DESIGN CONDITIONS -------------
                        CAPACITY   POWER  REFG T  AMB T    EIR    HEATER    PEAK LOAD   CAPACITY   POWER  REFG T   AMB T
     EQUIPMENT TYPE   FUNCTION  (MBTU/HR)  (KW)    (F)     (F)   (FRAC)    (KW)     (MBTU/HR)   (MBTU/HR)   (KW)    (F)     (F)
    ----------------  --------  --------  ------  ------  ------  ------  ------   ----------  ----------  ------  ------  ------

    VRF-HEAT-PUMP     Cooling     0.090     9.0    43.0    95.0   0.340   0.050      0.235       0.087      9.7    43.0   103.3
                      Heating    -0.100     8.2   115.0    43.0   0.280            -0.076      -0.074      7.1   115.0    20.1


           COOL LOAD  HEAT LOAD  ELEC USE  AUX ENERGY   -------- Number of hours within each PART LOAD range --------  TOTAL
       SUM   (MBTU)    (MBTU)     (KWH)      (KWH)      00   10   20   30   40   50   60   70   80   90  100   RUN
MON   PEAK (KBTU/HR) (KBTU/HR)   (KW)       (KW)        10   20   30   40   50   60   70   80   90  100    +   HOURS
---   ---- ---------- ---------- ---------- ---------- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----

JAN   SUM     0.208    -7.191     10.997     25.460 COOL   0    0    0    0    1    3    0    0    0    0    0     4
      PEAK   54.229   -89.810      2.910      0.050 HEAT 174  134   65   40   20    7    3    1    1    2    1   448
      DAY/HR 23/15      7/ 8      23/15       2/10 ELEC   0    0    1    3    0    0    0    0    0    0    0     4

FEB   SUM     2.506    -3.553    146.165     15.733 COOL   0    1    2    1   12   15    3    1    3    5    0    43
      PEAK   98.669   -66.739      6.664      0.050 HEAT 160   75   41   18    4    2    0    2    0    0    0   302
      DAY/HR 27/15      9/ 8      27/16       2/ 9 ELEC   0    3   11   20    0    1    4    4    0    0    0    43

MAR   SUM     4.011    -1.293    262.967     13.292 COOL   3    8    7    9   11    5    1    3    8   10    7    72
      PEAK  101.218   -25.281      7.402      0.050 HEAT 132   42   11    0    0    0    0    0    0    0    0   185
      DAY/HR 20/13      6/ 8      20/16       1/ 1 ELEC   3   12   19   10    0    4   14    5    5    0    0    72

APR   SUM    11.510    -0.313    827.397      9.980 COOL  12   12   11    7    9    6    2    6   19   31   50   165
      PEAK  101.346   -22.319      8.250      0.050 HEAT  43    8    2    0    0    0    0    0    0    0    0    53
      DAY/HR 16/13      6/ 8      29/16       1/22 ELEC  14   17   13   12    2    7   22   33   40    5    0   165

MAY   SUM    19.059     0.000   1467.425      3.200 COOL  14   35   18   17   13   12   12   12   27   31   96   287
      PEAK  105.469     0.000      9.131      0.050 HEAT   0    0    0    0    0    0    0    0    0    0    0     0
      DAY/HR  5/12      0/ 0      31/16       1/ 3 ELEC  24   37   18   15   11   16   28   39   71   27    1   287

JUN   SUM    24.209     0.000   1979.295      0.700 COOL  19   35   27   26   23   19   13   12   13   34  148   369
      PEAK  105.746     0.000      9.727      0.050 HEAT   0    0    0    0    0    0    0    0    0    0    0     0
      DAY/HR 22/11      0/ 0      16/17       1/ 3 ELEC  33   42   24   23   24   14   22   36   62   65   24   369

JUL   SUM    27.935     0.000   2408.057      0.050 COOL  25   31   33   24   24   17   15   11   15   25  197   417
      PEAK  102.170     0.000      9.926      0.050 HEAT   0    0    0    0    0    0    0    0    0    0    0     0
      DAY/HR 14/11      0/ 0      24/17       5/ 6 ELEC  39   45   29   16   14   20   16   31   57   91   59   417

AUG   SUM    25.330     0.000   2193.060      0.050 COOL  37   30   27   18   21   18   19   11   20   19  173   393
      PEAK  104.572     0.000      9.925      0.050 HEAT   0    0    0    0    0    0    0    0    0    0    0     0
      DAY/HR 12/11      0/ 0       7/17      27/ 7 ELEC  47   40   21   22   15   18   19   27   56   74   54   393

SEP   SUM    22.300     0.000   1815.164      0.750 COOL  37   28   15   18   15   14   10   14    6   19  160   336
      PEAK  102.168     0.000      9.537      0.050 HEAT   0    0    0    0    0    0    0    0    0    0    0     0
      DAY/HR  9/11      0/ 0       4/17      12/ 4 ELEC  42   35   18   16   14   10   18   27   70   66   20   336

OCT   SUM    16.722    -0.071   1240.514      5.310 COOL  12   12    7   11   15   16   10   11    9   17  107   227
      PEAK  105.727    -8.119      8.891      0.050 HEAT  21    0    0    0    0    0    0    0    0    0    0    21
      DAY/HR 27/16     13/ 8       5/14       1/ 6 ELEC  16   12   19   16   14   11   12   46   58   23    0   227

NOV   SUM     5.474    -1.948    359.169     13.800 COOL   1    1    1    1    6    7   12    6    4    9   23    71
      PEAK  102.338   -39.087      7.501      0.050 HEAT 127   57   21    6    1    0    0    0    0    0    0   212
      DAY/HR  4/11     30/ 8      25/14       1/ 1 ELEC   1    2    4   15    9    5    4   19   12    0    0    71

WLHP                                                     DOE-2.3-D22v  12/07/2009    14:02:53  BDL RUN  1

REPORT- PS-H Loads and Energy Usage for     VRF-Cond                                    WEATHER FILE- CZ12RV2 WYEC2
-------------------------------------------------------------------------------------------------(CONTINUED)--------

DEC   SUM     0.274    -6.170     14.500     24.828 COOL   0    0    0    0    1    4    0    0    0    0    0     5
      PEAK   61.282   -82.369      3.206      0.050 HEAT 176  140   70   24   11    8    1    0    1    2    0   433
      DAY/HR  7/13     23/ 8       7/13       1/ 9 ELEC   0    0    1    4    0    0    0    0    0    0    0     5
             ========== ========== ========== ========== ==== ==== ==== ==== ==== ==== ==== ==== ==== ==== ==== ====

Yr    SUM   159.538   -20.539  12724.711    113.153 COOL 160  193  148  132  151  136   97   87  124  200  961  2389
      PEAK  105.746   -89.810      9.926      0.050 HEAT 833  456  210   88   36   17    4    3    2    4    1  1654
      MON/DAY 6/22      1/ 7       7/24       1/ 2 ELEC 219  245  178  172  103  106  159  267  431  351  158  2389

 Number of Hours Overloaded  Cool: 3147  Heat:    0
```

CONDENSING-UNIT Hourly Report Variables

Variable-List Number	Variable in FORTRAN Code	Description
1	cu.CoilOnHt	Fraction of hour indoor heating coils are active
2	cu.CoilOnCl	Fraction of hour indoor cooling coils are active
3	cu.fCycle	Adjustment to run time to offset cycling loss
4	cu.FracOn	Fraction of hour unit runs
5	cu.SST	Saturated suction temperature, at unit
6	cu.SSTcoil	Saturated suction temperature, at indoor units
7	cu.ECTcl	Entering condensing temperature, cooling mode
8	cu.QcoilCl	Indoor coil cooling load, total over hour
9	cu.QcoilCl'	Cooling load, when outdoor unit is actually running
10	cu.CapfTcl	Cooling capacity adjustment factor, f(SST, ECTcl)
11	cu.QcapCl	Cooling capacity
12	cu.PLRcl	Cooling part-load ratio
13	cu.EIRfPLRcl	Cooling EIR adjustment, f(PLRcl)
14	cu.EIRfTcl	Cooling EIR adjustment, f(SST, ECTcl)
15	cu.EIRcl	Cooling adjusted EIR, excluding cycling
16	cu.kWcl	Cooling compressor power
17	cu.SCT	Saturated discharge temperature, at unit
18	cu.SCTcoil	Saturated discharge temperature, at coils
19	cu.ECTht	Entering outdoor temperature, heating mode (outdoor wetbulb if air-cooled)
20	cu.QcoilHt	Indoor coil heating load, total over hour
21	cu.QcoilHt'	Heating load, when outdoor unit is actually running
22	cu.CapfTht	Heating capacity adjustment factor, f(SCT, ECTht)
23	cu.DefCap	Defrost degradation factor; PLR = QcoilHt'/(QcapHt*DefCap)
24	cu.QcapHt	Heating capacity, unadjusted for defrost
25	cu.PLRht	Heating part-load ratio
26	cu.EIRfPLRht	Heating EIR adjustment, f(PLRht)
27	cu.EIRfTht	Heating EIR adjustment, f(SCT, ECTht)
28	cu.EIRht	Heating adjusted EIR, excluding cycling
29	cu.kWht	Heating compressor power
30	cu.kWaux	Auxiliary power
31	cu.kWcrank	Crankcase heater power
32	pe.kWtotal	Total power of compressor, auxiliary, crankcase; excludes indoor units
33	cu.Qcond	Condenser heat rejected (negative is heat pump absorbed)

PIU TERMINAL ENHANCEMENTS

Introduction

Powered-induction unit terminals utilize a fan to induce air from a secondary source and mix it with primary air supplied by a central air handler. The terminal exists in 3 major configurations:

1. <u>Parallel</u> - The fan draws air from the secondary air stream only; the blower runs intermittently. This terminal type may be attached to either a single duct system, such as VAV, or a dual-duct system. If attached to a dual-duct system, it draws its primary air only from the cold deck.

2. <u>Series</u> - The fan draws air from both the secondary and primary air streams; the blower runs all the time. This terminal type may be attached to either a single duct system, such as VAV, or a dual-duct system. If attached to a dual-duct system, it draws its primary air only from the cold deck.

3. <u>VAV booster fan</u> - There is no source of secondary induced air. Instead the fan assists the flow from the primary air supply. This strategy is sometimes used with underfloor supply plenums, where the plenum pressure is too low to provide the necessary static for the terminal.

Enhancements now allow:

1. The source of the induced secondary air to be specified,

2. Variable-speed PIU fans,

3. The "VAV booster fan" configuration

Building Description Language Changes

For completeness and maximum understanding, all keywords pertaining to PIU systems are reproduced here, both new and existing. For brevity, the descriptions of existing keywords may be edited to address only what is relevant to PIU terminals.

Zone
TERMINAL-TYPE
For single-duct, dual-duct, and multizone central air-handlers, takes a code-word that specifies the type of terminal serving the zone. The same type of terminal box does not have to be used for the entire system. For example, a PIU system will typically contain a mixture of fan powered terminal boxes and regular VAV or constant-volume reheat units. A subset of the allowed code-words are (others exist for other system types):

SVAV	Regular VAV or constant-volume box. ("SVAV" stands for "Standard Variable Air Volume.") This terminal type may be attached to either a single duct system, such as VAV, or a dual-duct system. If attached to a dual-duct system, it draws only from the cold deck.
SERIES-PIU	The fan draws air from both the secondary and primary air streams; the blower runs all the time. This terminal type may be attached to either a single duct system, such as VAV, or a dual-duct system. If attached to a dual-duct system, it draws its primary air only from the cold deck. See also INDUCED-AIR-SRC, ZONE-FAN-RUN, and ZONE-FAN-CTRL for more information on configuring this terminal.

PARALLEL-PIU	The fan draws air from the secondary air stream only; the blower runs intermittently. This terminal type may be attached to either a single duct system, such as VAV, or a dual-duct system. If attached to a dual-duct system, it draws its primary air only from the cold deck. See also INDUCED-AIR-SRC, ZONE-FAN-RUN, and ZONE-FAN-CTRL for more information on configuring this terminal.
SUBZONE	specifies a that this terminal is a subzone of another terminal, such as SVAV, SERIES-PIU, DUAL-DUCT, etc. The MASTER-ZONE specifies the zone to which this zone is slaved. A MASTER-ZONE may have any number of subzones. The MASTER-ZONE cannot be another subzone.

For single-zone systems such as SZRH, PSZ, PVVT or RESYS2, this keyword is unused. The terminal type is set automatically by the program based on the SYSTEM:CONTROL-ZONE. The control zone is the zone that will have the thermostat that controls the operation of the air handler. All other zones in the system, if any, are forced to be SUBZONEs and may have the optional control as described for subzones.

For unitary systems such as FC or PTAC, this keyword is also unused. Each zone defined in the system is the control zone for the individual air handler that the program defines for the zone. No subzones are allowed.

MASTER-ZONE
for TERMINAL-TYPE = SUBZONE, specifies the master zone that also supplies air to the subzone. The MASTER-ZONE must belong to the same system. It can be any of the other TERMINAL-TYPEs, but cannot be another SUBZONE.

INDUCED-AIR-SRC
for induction terminals (TERMINAL-TYPE = SERIES-PIU, PARALLEL-PIU, TERMINAL-IU, and CEILING-IU), specifies the source of the induced air:.

ZONE-RECIRC	The induced air is recirculated directly from the zone served by the terminal.
RETURN-PLENUM	The induced air is drawn from the return plenum serving the zone (ZONE:RETURN-PLENUM). The induced-air temperature is the plenum temperature. More than one zone may use the same return plenum; in which case the return temperature is the weighted average of all zonal return flows, adjusted for plenum heat gains.
RETURN-AIR	The induced air is drawn from the return duct downstream of any return plenums, if any, and immediately ahead of the return fan, if any. The induced-air temperature is the return temperature.
SUPPLY-AIR	For a SERIES-PIU terminal, there is no induced air. Instead the fan assists the flow from the primary air supply. This strategy is sometimes used with underfloor supply plenums, where the plenum pressure is too low to provide the necessary static for the terminal. This keyword applies only to SERIES-PIU terminals. If this code word is specified for other induction terminal types, a message will be issued and the keyword will be changed to ZONE-RECIRC.

INDUCED-AIR-ZONE
No longer used; see INDUCED-AIR-SRC

MIN-FLOW-RATIO

Minimum allowable zone air supply flow rate, expressed as a fraction of design flow rate. Applicable to variable-volume type systems only. This keyword also appears in the SYSTEM command, where it is a system level keyword that applies to all zones in the system. Here, it is a zone level keyword that applies only to this zone, allowing different MIN-FLOW-RATIOs for each zone. MIN-FLOW-RATIO can be scheduled using MIN-FLOW-SCH.

For a powered-induction unit terminal (TERMINAL-TYPE = SERIES-PIU, PARALLEL-PIU), the MIN-FLOW-RATIO controls the primary air supply. HMIN-FLOW-RATIO controls the minimum flow ratio of a variable-volume fan.

HMIN-FLOW-RATIO

For TERMINAL-TYPE = SERIES-PIU or PARALLEL-PIU with ZONE-FAN-CTRL = VARIABLE-VOLUME, this keyword describes the minimum fan output when in the thermostat deadband.

HMAX-FLOW-RATIO

In general, specifies the ratio of the maximum (or fixed) heating airflow to the cooling airflow. The specific meaning varies according to the type of zone terminal.

For TERMINAL-TYPE = SERIES-PIU, ZONE-FAN-CTRL = VARIABLE-VOLUME, and THERMOSTAT-TYPE = REVERSE-ACTION, this keyword is the maximum allowed fan output when heating.

ZONE-FAN-RATIO

Multiplied by the design primary air flow rate, gives design flow rate of the PIU fan. This keyword fixes the fan flow relative to the cooling flow. It will not act to modify the cooling flow relative to the heating flow. If both ZONE-FAN-FLOW and ZONE-FAN-RATIO are specified, ZONE-FAN-FLOW takes precedence.

For TERMINAL-TYPE = PARALLEL-PIU, the default is the ratio of the design heating airflow to the design cooling airflow. As this may result in an unrealistically small fan, it may be desirable to specify this ratio.

For TERMINAL-TYPE = SERIES-PIU, the default is the ratio of the total discharge airflow to the cooling airflow, or 1.0, whichever is larger.

ZONE-FAN-FLOW

The design capacity of the PIU fan. If neither ZONE-FAN-RATIO nor ZONE-FAN-FLOW is specified, the program will size the fan.

For TERMINAL-TYPE = SERIES-PIU this is a straightforward process: The blower is sized to the maximum flow rate determined from ZONE-AIR:ASSIGNED-FLOW, AIR-CHANGES/HR or FLOW/AREA, or it is sized by the program from design-sizing peak heating and cooling loads. If the design heating airflow is larger than the design cooling airflow, the PIU fan will be sized to match the heating airflow; the cooling airflow will be allowed to be less so that there will always be some induced air, even at peak cooling.

For TERMINAL-TYPE = PARALLEL-PIU, if ZONE-FAN-FLOW is not input, the blower is sized from the heating peak. The ZONE-level cooling air flow keywords are assumed to refer to the primary air from the central system. The zone heating airflow keywords (HASSIGNED-FLOW, HFLOW/AREA, etc.) are assumed to apply to the fan, but only if ZONE-FAN-FLOW is not specified. It is recommended that you explicitly size the fans, since the use of the heating peak to size the parallel PIU might result in an unrealistically small fan.

ZONE-FAN-KW/FLOW

The power of the fan per unit flow rate for TERMINAL-TYPE = SERIES PIU or PARALLEL-PIU.

ZONE-FAN-T-SCH
No longer used. See ZONE-FAN-RUN.

ZONE-FAN-RUN
For TERMINAL-TYPE = PARALLEL-PIU or SERIES-PIU, accepts a code word specifying when the terminal fan operates:

HEATING-ONLY	the default for PARALLEL-PIU terminals, specifies that the terminal fan runs when the zone temperature is in the heating band. This mode is also supported for SERIES-PIU terminals.
HEATING/DEADBAND	specifies that the terminal fan runs in both the heating and deadbands. In other words, the fan runs whenever the zone temperature is below the cooling band. This strategy is most commonly used for PARALLEL-PIU terminals, but is also supported for SERIES-PIU terminals.
CONTINUOUS	the default for SERIES-PIU terminals, specifies that the terminal fan runs continuously whenever the AHU fan is on. This strategy is also supported for PARALLEL-PIU terminals.
HEATING/COOLING	specifies that the terminal fan runs during both the heating and cooling modes, but is off in the deadband. This strategy is most commonly used with SERIES-PIU terminals, but is also supported for PARALLEL-PIU terminals.

If the central fan is scheduled off, but SYSTEM:NIGHT-CYCLE-CTRL is active, then the terminal fan will operate in accordance with the above control.

ZONE-FAN-CTRL
For TERMINAL-TYPE = PARALLEL-PIU or SERIES-PIU, accepts a code word specifying the airflow control mechanism for the terminal fan:

CONSTANT-VOLUME	the fan operates at a constant airflow all hours. This is the default for PARALLEL-PIU terminals. It is also the default for SERIES-PIU terminals whose INDUCED-AIR-SRC is not SUPPLY-AIR; or if SUPPLY-AIR, if the primary air supply is constant volume.
	If the zone fan is specified to be CONSTANT-VOLUME, but the terminal is a SERIES-PIU with a variable-volume primary air supply, then the fan will, by necessity, be variable-volume. In this case, it is assumed that the fan is constant-speed rather than variable-speed, and fan power will be modeled as linear with airflow; rather than using the ZONE-FAN-KW-FPLR curve.
VARIABLE-VOLUME	the fan is variable-volume. Power will vary in accordance with the ZONE-FAN-KW-FPLR keyword.

For PARALLEL-PIU terminals:

- The primary air flow (from the cold deck) is typically variable-volume, but will be constant-volume if the MIN-FLOW-RATIO = 1. Note that THERMOSTAT-TYPE = REVERSE-ACTION has no meaning for a parallel PIU terminal.

- The fan flow (induced air flow) is independent of the primary supply flow. The maximum fan flow is as specified by either the ZONE-FAN-FLOW, the HASSIGNED-FLOW, the cooling flow multiplied by ZONE-FAN-RATIO, or defaulted. The fan may be either constant-volume or variable according to this keyword. If the fan is variable-volume:

- The fan will be at minimum flow during the deadband and cooling (or off depending on ZONE-FAN-RUN).

- The fan will be variable-volume during heating. The minimum flow will be as specified or defaulted for the HMIN-FLOW-RATIO, where this keyword represents the ratio of the minimum fan flow to the maximum fan flow. Alternatively, you may specify MIN-FLOW/AREA.

For SERIES-PIU terminals with INDUCED-AIR-SRC = SUPPLY-AIR:

- This configuration has no induced air; the fan tracks the primary supply flow and boosts the static pressure. Airflow control is identical to a conventional VAV terminal; summarized as follows. The primary supply flow is at minimum flow in the deadband, as specified by the MIN-FLOW-RATIO or defaulted. In the heating mode, the primary flow will increase if the THERMOSTAT-TYPE = REVERSE-ACTION. The maximum flow during heating will be as defaulted or specified by the HMAX-FLOW-RATIO. If THERMOSTAT-TYPE = PROPORTIONAL, flow will be constant in the heating mode, but HMIN-FLOW-RATIO may be specified to cause a jump in heating airflow compared to the deadband.

- If ZONE-FAN-CTRL = CONSTANT-VOLUME, but the primary airflow is variable-volume, then the fan must also be variable-volume, as there is no induced airflow. In this case, the fan is assumed to be constant-speed but variable-volume, and fan power will be adjusted linearly with flow.

For SERIES-PIU terminals with INDUCED-AIR-SRC = ZONE-RECIRC, RETURN-PLENUM, or RETURN-AIR:

- The primary air flow (from the cold deck) is typically variable-volume in the cooling mode, but will be constant-volume if the MIN-FLOW-RATIO = 1. The primary supply flow is at minimum flow in the deadband and heating modes.

- The fan flow is the sum of the primary airflow (from the cold deck) and the induced airflow. The fan may be either constant-volume or variable-volume as specified by ZONE-FAN-CTRL. The maximum fan flow will be at least the design primary airflow, but may be greater as specified by either the ZONE-FAN-FLOW, the HASSIGNED-FLOW, or the cooling flow multiplied by ZONE-FAN-RATIO.

  If the fan is constant volume, then the supply to the space will be constant. The induced airflow will make up the difference between the fixed fan flow and the primary airflow.

  If the fan is variable-volume:

  o In the thermostat deadband, the fan will be at minimum flow (or off depending on ZONE-FAN-RUN). HMIN-FLOW-RATIO specifies the minimum flow ratio of the fan; by default it is the same as MIN-FLOW-RATIO of the primary airflow. You may alternatively specify HMIN-FLOW/AREA instead of HMIN-FLOW-RATIO.

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o In the cooling mode, the fan will track the primary airflow. Normally, the fan will exactly track the airflow; except under two conditions: 1) ZONE-FAN-RATIO is specified greater than 1.0; in this case the fan will deliver proportionately greater airflow over the cooling range. 2) The HMIN-FLOW-RATIO is greater than the MIN-FLOW-RATIO; in this case the fan will deliver the HMIN-FLOW-RATIO at the deadband, and exactly match the primary flow at maximum cooling.

o In the heating mode, the fan will modulate open if THERMOSTAT-TYPE = REVERSE-ACTION. Otherwise, the fan will remain at the deadband flow. The maximum flow ratio during heating is the HMAX-FLOW-RATIO, which defaults based on the design heating flow.

ZONE-FAN-KW-FPLR

For TERMINAL-TYPE = PARALLEL-PIU or SERIES-PIU, and ZONE-FAN-CTRL = VARIABLE, accepts the U-name of a CURVE-FIT that modifies the fan power for variable-volume operation. This CURVE-FIT may be either LINEAR, QUADRATIC, or CUBIC; and should be normalized to 1.0 at full-flow. A cubic curve will normally give the best results. To give reliable results, the curve should be fitted through the smallest airflow ratio that you expect (MIN-FLOW-RATIO or its default for SERIES-PIU boxes, and HMIN-FLOW-RATIO or its default for PARALLEL-PIU boxes).

If this zone also serves subzones, this curve will be used to calculate the power consumption of the master zone only. Power for the combination of master and subzones will then be linearly scaled by the ratio of (CFMmaster + CFMsubzones) / CFMmaster.

CHW-LOOP ECONOMIZER COOLING

Introduction

In colder winter climates, a cooling tower may be able to produce condenser water at a temperature lower than required in the chilled-water loop. During these times, this cold condenser water may be used to directly cool the chilled-water loop using a heat exchanger in lieu of mechanical cooling. This "free cooling" can be simulated using one of three options:

1. <u>Water-side economizer</u> - simulates a heat exchanger that couples the condenser water loop to the chilled-water loop. This heat exchanger is located upstream of the chiller(s), and can satisfy up to 100% of the cooling load when conditions are suitable. If the water-side economizer cannot handle 100% of the load, it can act to precool the return water; thereby reducing the load on the chillers. This option uses a CHILLER of TYPE = WATER-ECONOMIZER.

2. <u>Thermocycle</u> - simulates a centrifugal chiller configured to allow the refrigerant to bypass the compressor and passively transfer heat between the evaporator and condenser (boiling in the evaporator and condensing in the condenser; without the use of the compressor). For more information on this option, refer to the chiller section "Thermocycle Option in Centrifugal Chillers"

3. <u>DX water-side economizer - A direct-expansion air conditioner may have an additional coil that is attached to the condenser loop to provide free cooling. This configuration does not couple a chilled-water loop to a condenser loop, and is covered in the SYSTEM section.</u>

For free cooling to work, it is necessary that the cooling towers be controlled to produce very cold water when the ambient conditions are suitable. However, it would be a waste of tower energy to attempt to produce very cold water when the ambient conditions are unsuitable. Keywords are included for this purpose. A WLHP loop can also be used for free cooling, however it does not have any active temperature control; the supply temperature is whatever is available in the lake.

To maximize free cooling, some form of temperature reset should be employed in the chilled-water loop. Savings will be maximized by using COOL-SETPT-CTRL = LOAD-RESET, although OA-RESET or SCHEDULED may also work.

Building Description Language Changes

Circulation-Loop
START-WSE-WB
in the condenser-water loop, specifies the outdoor wetbulb temperature below which free cooling will be attempted. The loop's COOL-SETPT-CTRL will be overridden, and the heat-rejection devices will be controlled to the WSE-SETPT.

You may use either START-WSE-WB and/or START-WSE-DB. Wetbulb initiation is most appropriate for evaporative devices (COOLING-TWR or FLUID-COOLER); drybulb initiation is most appropriate for a drycooler. If you specify both, either criteria will initiate the free cooling mode. If you do not specify either the START-WSE-WB or the START-WSE-DB, then no active waterside economizer control will exist in the condenser loop. However, the loop may still be cold enough at times depending on the loop setpoint.

START-WSE-DB
in the condenser-water loop, specifies the outdoor drybulb temperature below which free cooling will be attempted. The loop's COOL-SETPT-CTRL will be overridden, and the heat-rejection devices will be controlled to the WSE-SETPT.

You may use either START-WSE-WB and/or START-WSE-DB. Wetbulb initiation is most appropriate for evaporative devices (COOLING-TWR or FLUID-COOLER); drybulb initiation is most appropriate for a drycooler. If you specify both, either criteria will initiate the free cooling mode. If you do not specify either the START-WSE-WB or the START-WSE-DB, then no active waterside economizer control will exist in the condenser loop. However, the loop may still be cold enough at times depending on the loop setpoint.

WSE-SETPT
in the condenser loop, when START-WSE-WB or START-WSE-DB initiates the free cooling mode, the loop's COOL-SETPT-CTRL will be overridden, and the heat-rejection devices will be controlled to this setpoint. To maximize free cooling, this setpoint should be at least several degrees below the chilled-water setpoint.

BYPASS-WSE
in a chilled-water loop having a water-side economizer (a CHILLER of TYPE = WATER-ECONOMIZER), specifies whether the economizer should be bypassed when it is inactive. YES means the economizer will be bypassed, NO means that it will remain in the loop flow at all times. If not bypassed, the economizer's head will be imposed on the loop pumps at all times, reducing the potential energy savings of staged or variable-speed pumps.

Chiller, Water-Economizer

While a water-side economizer is not actually a chiller, it is included as a chiller of TYPE = WATER-ECONOMIZER because it shares many features common to chillers. It attaches to both a CHW-LOOP and a CW-LOOP, and the keywords describing head losses and rated vs. design flows all apply. It may also have a condenser pump (CW-PUMP), but cannot have a chilled-water pump. It is assumed to consume no power, however the AUX-KW set of keywords is available.

A condenser-water loop may supply more than one water-side economizer, although this would be unusual. A given chilled-water loop may have more than one water-side economizer, although again this would be unusual.

The water-side economizer is located upstream of, and in series with, the chillers, and acts to precool the return water prior to entering the chillers. If the condenser water temperature is cold enough to satisfy the entire cooling load, then the chillers will not run. Otherwise, the water-side economizer will pick up as much of the load as possible, and the chillers will pick up the rest.

The condenser side of the economizer is in parallel with the chiller condensers. When autosizing, the condenser loop does NOT take into account the flow of the economizer, as it assumes that the economizer will not be operating simultaneously with the chillers during the peak period of the cooling design day. Subsequently, if the economizer is operating simultaneously with the chillers on a mild day, there is the potential for an excessive demand on the condenser loop. The program takes two steps to minimize this potential problem:

1. The design condenser-water flow through the economizer is limited to be not more than 80% of the design condenser loop flow.

2. As the cooling towers are producing very cold water during economizer operation, and the chillers will be lightly loaded, condenser flow through the chillers will be severely restricted to maintain sufficient condensing pressure, as described in the MIN-COND-T keyword.

The following keywords apply to the water-side economizer. Many of the keywords have meanings identical as already described in previous sections. Keywords having different meanings are discussed in detail.

CAPACITY
TONS
specifies the economizer capacity at the rated chilled-water and condenser-water flows, and at a chilled/condenser-water inlet temperature differential of RATED-WSE-TD.

This capacity, together with the rated chilled-water flow, condenser-water flow, and the RATED-WSE-TD, is used to calculate the required UA product of a counterflow heat-exchanger. This UA is used on an hourly basis, together with the actual chilled-water flow and inlet temperatures, to determine whether the economizer can satisfy the cooling load, and the resulting condenser-water flow.

CAPACITY-RATIO
this keyword normally describes the fraction of the design-sizing chilled-water loop LOAD; here it means the fraction of the design-sizing loop FLOW. If neither CAPACITY nor CAPACITY-RATIO is specified, the economizer design flow will default to the design loop flow divided by the number of economizers attached to the loop.

If the loop flow during economizer operation is larger than what the economizer is sized to handle, then the excess will be bypassed around the economizer. Note that, for a chilled-water loop supplying coils with two-way valves, loop flow during economizer operation may be substantially less than design. For this reason, you may want to specify a capacity ratio significantly smaller than 1.0

CHW-LOOP, RATED-CHW-FLOW,
RATED-CHW-DT,
CHW-HEAD,
CHW-STATIC-HEAD ,
CHW-MAX-FLOW
identical to other chillers. Note that you cannot attach a CHW pump directly to an economizer. Either a loop pump must be defined, or pumps must be attached to the conventional chillers.

CW-LOOP,
RATED-CW-FLOW,
RATED-CW-DT,
DESIGN-CW-FLOW,
DESIGN-CW-DT,
CW-HEAD,
CW-STATIC-HEAD,
CW-PUMP
identical to other chillers. Note that you can attach a CW pump directly to an economizer. Like other chillers, if the condenser loop does not have a pump, then this pump is mandatory. CW-FLOW-CTRL does not apply, as condenser flow is always assumed to be variable (CHW temperature is maintained by varying the condenser flow).

RATED-WSE-TD
is the temperature differential between the entering chilled water and the entering condenser water at which the specified capacity or capacity-ratio exists. This temperature differential must be larger than either the chilled-water temperature drop or the condenser-water temperature rise, or else the condenser water could produce chilled-water colder than itself. The program checks for this condition, and will abort with an error message if this condition is not met. If the RATED-CHW-FLOW is 2.4 gpm/ton, this corresponds to a 10°F temperature drop. A reasonable RATED-WSE-TD is then in the range of 12-15°F.

MIN-WSE-TD

is the minimum temperature differential between the entering chilled water and entering condenser water necessary to start the economizer. To prevent an excessive flow demand on the condenser loop, the temperature differential must be at least this value for the controls to activate the economizer.

AUX-KW & related

are identical to other chillers.

Chiller, Centrifugal with Thermocycle

A thermocycle operates in an "all or none" mode. If the condenser water temperature is cold enough to satisfy the entire chiller load, then the thermocycle will operate and the compressor will remain off. Otherwise, the compressor will run. The number of hours the thermocycle operates can be determined by reviewing report PS-C or PS-H and comparing the total number of load hours to the total number of electric hours.

THERMOCYCLE-CAP

For water-cooled centrifugal chillers only, specifies the fraction of the rated chiller capacity that can be recovered using a thermocycle. There is no default value; if not specified, then thermocycle cooling does not exist. This fraction is always less than the rated capacity, and is assumed to occur at the rated chilled-water and condenser-water flows, and a chilled-water vs. condenser-water inlet-temperature differential specified by the RATED-WSE-TD.

The program uses this value to calculate a rated thermocycle load. This load, together with the rated chilled-water flow, condenser-water flow, and the RATED-WSE-TD, is used to calculate the required UA product of a counterflow heat-exchanger. This UA is used on an hourly basis, together with the actual chilled-water flow and inlet temperatures, to determine whether the thermocycle satisfy the chiller load, and the resulting condenser-water flow.

RATED-WSE-TD

When THERMOCYCLE-CAP is specified, is the temperature differential between the entering chilled water and the entering condenser water at which the specified capacity exists. This temperature differential must be larger than either the chilled-water temperature drop or the condenser-water temperature rise, or else the condenser water could produce chilled-water colder than itself. The program checks for this condition, and will abort with an error message if this condition is not met.

UNDERFLOOR HVAC AIR DISTRIBUTION

Introduction

Conventional variable-volume systems typically supply air at the ceiling level via air diffusers. These diffusers are designed to introduce the relatively cold supply high at a velocity sufficiently high so that the supply air thoroughly mixes with the room air, thereby conditioning the space while minimizing the effects of cold drafts. These systems are typically designed to achieve at least a 20°F (11°C) differential between the supply air and the return air temperatures; so that supply air at 55°F (13°C) can maintain the space in the 75°F (24°F) range. By reducing the supply temperature, it is possible to increase the supply/return differential to minimize the supply volume and attendant fan energy, however this increases the probability that cold, dense air will "dump" down into the occupied zone, rather than mixing. This dumping effect can be especially pronounced in variable-air volume systems during low cooling demands and attendant low velocities. For this reason 55°F air is typically used.

A conventional VAV system provides heating to a space by reheating the supply air. While the ventilation requirement to maintain air quality may allow a VAV box to close down to less than 15% airflow prior to reheat, reheat at the correspondingly low velocity is often problematic. Rather than mixing with the room air, a portion of the hot buoyant air may float at the ceiling level and flow directly to the return grills, bypassing the space completely. To avoid this problem, the VAV boxes must either not close down as far as they otherwise could, or must re-open as heating is introduced. The result in either case is an increase in reheat energy.

In contrast to the conventional HVAC system, an underfloor HVAC air distribution (UFAD) or displacement ventilation (DV) system does not use overhead air diffusers; instead they supply air at the floor level, either via a subfloor plenum (UFAD), or sidewall diffusers near the floor (DV). The supply air is introduced at a low velocity, with the intent that it not mix thoroughly in the space. Instead, the cool dense air stratifies so that the "occupied zone" near the floor is at a comfortable temperature, and the air in the "unoccupied zone" near the ceiling is warmer. The air returns are at the ceiling, so that the warmest air is drawn off and returned to the air handler.

A UFAD/DV system cannot typically utilize 55°F (13°C) supply air, as that could create uncomfortable drafts in the occupied zone. Instead, air is introduced in the range of 60°F-65°F (16-18°C). If introduced at a sufficiently low velocity, this air will remain near the floor level, and the majority of air in the space will be relatively still. Heat-generating equipment in the space, such as task lights and computer equipment, may then generate "heat plumes" that convectively rise off the equipment and flow into the upper unoccupied region of the space. Plumes may also be created by warm exterior walls and windows, and/or by sunlight striking surfaces within the space. To the extent that these heat plumes successfully escape to the return, less cooling air will be needed. The goal in an UFAD design is to design and locate the floor-level diffusers in a manner such that the heat plumes are maximized. If the upper region of the space can be maintained in the 80°-85°F (27-29°C) range, then the net airflow required is approximately the same as for a conventional system.

The thermodynamics of this process are controversial at this time (2008-2011). The following is a summary of some of the key issues:

- Peak airflow - For a UFAD/DV system to have the same airflow as a conventional system, the system must have at least as large a supply/return air temperature differential. If the typical supply temperature is 60°F-65°F (16-18°C), then the air temperature near the ceiling must be at least 80-85°F (27-29°C).

  Some theoretical studies have been conducted to investigate the magnitude of the radiant exchange between ceiling and floor. Assuming typical surface emissivities, some of these studies suggest that such a large supply/return temperature differential is not possible in a stratified space. With this degree of stratification, radiant energy exchange between the ceiling and floor may overwhelm the maximum possible effect of thermal plumes. At the time of this writing, a review of available published field measurements

also does not support this claim. Therefore, UFAD/DV systems may actually have a smaller supply/return differential than a conventional system, and require a higher airflow.

- Economizer savings - Because UFAD/DV systems typically have a higher supply air temperature than a conventional overhead system, UFAD/DV systems are believed to achieve higher energy efficiency via increased economizer savings. However, economizer savings are proportional to the airflow multiplied by the differential between the *return air* and the outside air, not the supply air. Therefore, to achieve increased economizer savings, a UFAD/DV system must have either: 1) The same airflow and a warmer return air temperature than a conventional overhead system; 2) A smaller air flow and a higher return temperature; or 3) A larger airflow and a lower return temperature.

    A partial review of field measurements published to date does not appear to support any of these scenarios, other than possibly #3. But note that, during the times that the economizer is active, cooling loads are typically not at peak and a conventional overhead system usually does not require 55°F (13°C) supply air. If the supply air temperature of a conventional system is reset based on load (as required by many Codes and Standards), then it may achieve comparable or greater economizer savings than a UFAD/DV system. For both types of systems, increased economizer savings are achieved at the expense of higher fan energy.

- Diffuser short-circuiting - As noted earlier in this section, during heating a conventional overhead system may experience stratification and diffuser short-circuiting problems. DV systems can also have the same problem, as warm air will tend to immediately rise to the ceiling rather than mix in the occupied zone. UFAD systems usually cannot be used for heating without including fan-boosted reheat terminals near the perimeter. UFAD/DV systems may require the use of separate systems for heating, such as baseboards.

- Plenum short-circuiting - UFAD systems typically utilize a supply plenum under the floor of the occupied zone. If return plenums are also used in a multi-story building, then cool supply plenums may be directly above warm return plenums. Heat transfer between these two plenums can be significant, producing a temperature change in both air streams in the range of 5-10°F (3-5°C), or 25-50% of the air's heat transport capacity. The "thermal short circuiting" between the supply and return plenums acts to increase the required airflow and power, and further reduces the possibility of economizer savings.

    The supply plenums typically also loose heat directly to the outdoors via conduction and exfiltration.

    Note that conventional overhead systems also experience some thermal short-circuiting from supply ducts in return plenums, although usually not as much.

- Thermal mass and reset - Because conventional systems have lightweight ducting, they can readily utilize supply air reset in the morning without incurring a penalty in the afternoon. UFAD systems typically have supply plenums in direct contact with a concrete floor. The thermally massive concrete floor will increase the peak afternoon cooling load if the supply temperature is reset lower in the afternoon. A UFAD system may also have higher cooling start-up/shut-down loads during warm weather, as the floor slab under the supply plenum must be cooled to the supply temperature in the morning, and gains the heat back at night.

- Air leakage - While it is well understood that most ducting will have some air leakage, leakage can be especially problematic in UFAD systems.

- Minimum airflow - Conventional systems may be designed with minimum airflows as low as 15% of design in many cases. A turndown this severe in a UFAD system may result in poor air distribution and excessive temperature gains in the supply plenum.

- Fan-boosted perimeter terminals - A supply plenum in a UFAD system often serves both interior and perimeter spaces. Because the perimeter spaces typically require higher cooling airflows and/or have winter heating loads, fan-boosted VAV terminals may be used to draw the necessary volume of air from the supply plenum. The fans in these terminals may add substantially to the fan energy budget of the building.

The following describe features implemented in the program to allow modeling of UFAD/DV systems. The algorithms at this point are relatively simple, and do not take into account radiative coupling between the lower occupied and upper unoccupied areas of the zone. However, they do allow thermal plumes, diffuser bypassing, and supply/return short-circuiting to be modeled. The algorithms may be enhanced in the future if additional field data demonstrate that UFAD/DV systems can achieve the stratification necessary to compete with conventional overhead systems, and theoretical models are developed that accurately track the performance of actual systems in buildings. At this time, such models are not known to exist.

Diffuser Losses in Conventional Overhead and DV Systems

As described above, in a conventional air distribution system both the supply and return diffusers are typically located on the ceiling. As a result, some of the supply air may not fully mix with the space, but may instead short-circuit the space and flow directly into the return. This is particularly true for VAV systems in the heating mode, but may also be true in DV systems during heating.

The following zone keywords allow diffuser losses to be approximated in the heating, deadband, and cooling modes.

ZONE:DIFFUSER-LOSS-HT

Specifies the fraction of supply air supplied to the zone that short-circuits to the return during full heating (bottom of heating throttling range). The maximum zonal heat addition is reduced by this factor, and the zone return temperature is increased accordingly. For example, if an airflow of 100 cfm is needed to maintain setpoint, and the diffuser loss is 0.10, then the actual flow will be

CFM = CFMreqd / (1-DiffuserLoss)

CFM = 100 / (1-0.10) = 111 cfm

As the heating load decreases, the diffuser loss is prorated between this value and the deadband value.

ZONE:DIFFUSER-LOSS-DB

Specifies the fraction of supply air supplied to the zone that short-circuits to the return when the zone thermostat is in the deadband. The zonal heat extraction/addition will be reduced by this factor, and the zone return temperature adjusted.

ZONE:DIFFUSER-LOSS-CL

Specifies the fraction of supply air supplied to the zone that short-circuits to the return during full cooling. The maximum zonal heat extraction is reduced by this factor, and the zone return temperature is reduced accordingly. For example, if an airflow of 100 cfm is needed to maintain setpoint, and the diffuser loss is 0.10, then the actual flow will be

CFM = CFMreqd / (1-DiffuserLoss)

CFM = 100 / (1-0.10) = 111 cfm

As the cooling load decreases, the diffuser loss is prorated between this value and the deadband value.

UFAD/DV Thermal Plumes

For UFAD systems, the program currently supports one supply plenum per air handler. Refer to the SYSTEM:SUPPLY-PLENUM keyword for more information.

Thermal plumes are modeled using the following keywords. While intended for UFAD/DV systems, they may be used with any terminal type, and may be used in conjunction with the DIFFUSER-LOSS-HT, -CL, -DB keywords.

ZONE:PLUME-COOL

When an underfloor air distribution (UFAD) or displacement ventilation (DV) system is being modeled, specifies the fraction of the zone heat gains that create heat plumes at the maximum cooling airflow and/or minimum supply temperature. These heat plumes bypass the lower occupied zone of the space, and flow directly to the system return ducting or return plenum. While this keyword is primarily intended for modeling UFAD/DV systems, it is applicable to any system type.

Acceptable inputs range from -0.9 to 0.9. A value of 0.0 means that no heat plumes form in the space, while a value of 0.9 means that 90% of the heat gains are in heat plumes that flow directly to the return.

When the SYSTEM:SUPPLY-PLENUM is specified to model an UFAD system, this keyword defaults to 0.1, meaning 10% of the zone heat gains bypass the space and flow directly to the return. This plume effect occurs when the zone temperature is at the top of the thermostat's cooling throttling range. The default value is approximate, as research in this technology is in progress. The user should review available information and similar designs when selecting an appropriate value for this keyword. A value too high will result in the program overestimating the stratification effect, and underestimating the required supply air flow. A value too conservative will underestimate the potential energy savings of an UFAD/DV system.

When a SUPPLY-PLENUM is not specified, the default is 0.0; meaning no zone heat gains form plumes, and all of the heat gains are fully mixed in the space. This is the default for a conventional system. You may modify this value to approximate other configurations, with or without a SUPPLY-PLENUM.

The default is also zero for several of the terminal types, such as if the zone is the control zone of a single-zone system.

As the space temperature drops below the cooling setpoint, airflow in a VAV system is reduced and the plume effect may increase due to reduced turbulence and improved stratification. At minimum airflow, the plume effect is defined by the PLUME-DEADBAND.

ZONE:PLUME-DEADBAND

When an underfloor air distribution (UFAD) or displacement ventilation (DV) system is being modeled, specifies the portion of the zone heat gains that create heat plumes when the thermostat is in the deadband. These heat plumes bypass the lower occupied zone of the space, and flow directly to the return ducting or return plenum. The thermostat deadband is the region between the top of the heating control band, and the bottom of the cooling control band. In this region, airflow is at minimum (if VAV) and/or the supply temperature is neutral. While this keyword is primarily intended for modeling UFAD/DV systems, it is applicable to any system type.

Acceptable inputs range from -0.9 to 0.9. A value of 0.0 means that no heat plumes form in the space, while a value of 0.9 means that 90% of the heat gains are in heat plumes that flow directly to the return.

When the SYSTEM:SUPPLY-PLENUM is specified to model an UFAD system, this keyword defaults to 0.2, meaning 20% of the zone heat gains bypass the space and flow directly to the return when the thermostat is in the deadband range. When a SUPPLY-PLENUM is not specified, the default is 0.0, meaning no zone heat gains form plumes, and all of the heat gains are fully mixed in the space. This is the default for a conventional system. You may modify this value to approximate other configurations, with or without a SUPPLY-PLENUM.

The default is also zero for several of the terminal types, such as if the zone is the control zone of a single-zone system.

As the space temperature moves out of the deadband, airflow in a VAV system may increase and/or the supply temperature may increase/decrease. Plume effects at maximum heating and cooling are defined by the PLUME-HEAT and PLUME-COOL keywords.

ZONE:PLUME-HEAT

When an underfloor air distribution (UFAD) or displacement ventilation (DV) system is being modeled, specifies the portion of the zone heat gains that create heat plumes at the maximum heating airflow and/or maximum heating supply temperature. These heat plumes bypass the lower occupied zone of the space, and flow directly to the system return ducting or return plenum. While this keyword is primarily intended for modeling UFAD/DV systems, it is applicable to any system type.

Acceptable inputs range from -0.9 to 0.9. A value of 0.0 means that no heat plumes form in the space, while a value of 0.9 means that 90% of the heat gains are in heat plumes that flow directly to the return. When a SYSTEM:SUPPLY-PLENUM is specified, this keyword defaults to 0.0, meaning that none of the zone heat gains bypass the space and flow directly to the return. This is because little or no stratification of zone heat gains is expected when heat is added at the floor level.

As the space temperature rises above the heating setpoint toward the deadband, airflow in a VAV system may be reduced, and/or the supply temperature reduced. The plume effect may then increase due to improved stratification, as defined by the PLUME-DEADBAND.

SYSTEM:SUPPLY-PLENUM

Accepts the U-name of a plenum zone belonging to the same system. The program uses this plenum to supply air to all of the zones in the system. Only one supply plenum is allowed per system, but a system may have any additional number of return plenums. When this keyword is specified, the program automatically simulates an underflow air distribution system, using the values of ZONE:PLUME-HEAT, ZONE:PLUME-COOL, and ZONE:PLUME-DEADBAND to model the stratification effects. The user should review other keywords as discussed in the general section of this discussion to determine their applicability to this system type, and whether the defaults should be modified.

Like a return plenum, a supply plenum can have both exterior and interior walls that act to heat/cool the air flowing through the plenum. It is important to model these walls, as the heat gains can be significant. For example, consider a cold underfloor supply plenum on a floor directly above a warm return plenum. If the only insulation on the floor is the carpet above and the fireproofing below, the supply plenum may pick up 2°F-5°F of heat from the return plenum (even more at low airflows), and the return plenum will loose a similar amount. Uncontrolled, these short-circuited heat gains between the supply and return may increase the required airflow by 20%-100% above what might otherwise be required.

UFAD Fan-Boosted Perimeter Terminals

A supply plenum in a UFAD system often serves both interior and perimeter spaces. Because the perimeter spaces typically require higher cooling airflows, and/or have winter heating loads, fan-boosted VAV terminals may be used to draw the necessary volume of air from the supply plenum. These terminals may be modeled by specifying ZONE:TERMINAL-TYPE = SERIES-PIU and ZONE:INDUCED-AIR-SRC = SUPPLY-AIR. Note that the fans in these terminals may add substantially to the fan energy budget of the building.

Modeling Tips for Conventional vs. UFAD Systems

When comparing a UFAD HVAC system to a conventional VAV system, it is important to make sure that all important characteristics of each system are defined. The following is a summary of some of the most important characteristics of each.

Conventional Systems

- Supply plenum - Do not specify the SYSTEM:SUPPLY-PLENUM.

- Supply temperature - the SYSTEM:MIN-SUPPLY-T can be allowed to default to 55°F, which is the temperature delivered to the zone that determines the sizing of the VAV terminals. The SYSTEM:COOL-SET-T can be allowed to default; where the default is the MIN-SUPPLY-T minus the design duct temperature gain.

- Supply temperature reset - To minimize the reheat energy consumed, the supply air temperature can be reset using the SYSTEM:COOL-CONTROL = WARMEST and HEAT-CONTROL = COLDEST. This also maximizes the economizer savings.

- Coil bypass factor - The SYSTEM:COIL-BF can be allowed to default.

- Supply fan power - The fan power can be allowed to default if appropriate.

- Diffuser bypass to return - During VAV reheat, a significant portion of the warm supply air may float on the ceiling and bypass directly into the return. The DIFFUSER-LOSS-HT can significantly increase the heating energy.

- Chilled water temperature - If the HVAC system utilizes a chilled water plant, the chilled-water supply temperature can be allowed to default.

UFAD Systems

- Supply plenum - Specify one of the plenums to be a supply plenum via the SYSTEM:SUPPLY-PLENUM. Heat transfer between the supply plenum and adjacent return plenums can be significant (the supply plenum in the second and higher floors is immediately above the return plenum of the floor below). For this reason, it is important to define all demising interior walls to account for this effect.

- Supply temperature - the SYSTEM:MIN-SUPPLY-T should be specified to be in the 60°-65°F range, which is the temperature delivered to the zone that determines the sizing of the VAV terminals. The SYSTEM:COOL-SET-T can be allowed to default; where the default is the MIN-SUPPLY-T minus the design duct temperature gain, minus an estimated 3°F temperature rise in the SUPPLY-PLENUM.

- Supply temperature reset - The supply temperature can be reset (SYSTEM:COOL-CONTROL), but this may not be advisable. An underfloor supply plenum acts as a thermally-massive duct (assuming you have properly defined the concrete floor under the supply plenum). Raising the temperature of this duct during the morning hours and then dropping the temperature in the afternoon may significantly increase the peak cooling demand.

- Coil bypass factor - as a 65°F supply temperature may not provided adequate dehumidification with a conventional coil, UFAD systems typically utilize either a coil having a higher bypass factor, or utilize a face-and-bypass damper. This effect should be modeled by specifying the SYSTEM:COIL-BF to be in the range of 0.4

- Supply fan power - A UFAD system might use less fan energy per unit airflow if the static pressure requirement is less than the alternative conventional system. (Note that the drop in static is relatively small, as a conventional VAV box can operate with less than 0.5 inches pressure, and a UFAD system still requires plenum pressurization and pressurization control dampers.)

- Zone plume factors - The ZONE:PLUME-HEAT, -COOL, -DEADBAND have a critical impact on the required zone airflow. These factors should be chosen with care.

- Chilled water temperature - If the HVAC system utilizes a chilled water plant, the chilled-water supply temperature can be allowed to default. While the supply air temperature in a UFAD system may be warmer than in a conventional system, the higher coil bypass factors used for good humidity control still require cold chilled water.

- Fan boosted perimeter terminals - If the UFAD system uses fan-boosted VAV terminals in the perimeter zones that draw from the supply plenum, specify TERMINAL-TYPE = SERIES-PIU and INDUCED-AIR-SRC = SUPPLY-AIR.