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Heating, Ventilating, and Air Conditioning (HVAC) for Indoor Plant Environments without Sunlight



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0 Introduction

This Engineering Practice provides growers with the foundational information that will a) facilitate the understanding of HVAC equipment options that can be used to manage the indoor plant environment (IPE) and b) allow the grower to communicate knowledgeably with engineers, contractors, manufacturers, investors, and other growers.

The HVAC system selected, and air quality measures employed, affect plant growth and development.

To help facilitate the selection and design of the HVAC systems, it is important to establish the design criteria of the IPE. The mechanical engineer, in consultation with the grower, is responsible for sizing and selecting the HVAC equipment based on the psychrometrics of the IPE. The crop will determine the design criteria, including target temperature and humidity ranges, plant transpiration, irrigation control, lighting design and operation, and the envelope assemblies (wall, ceiling, etc.).

HVAC systems can be selected to control a single parameter (e.g.: temperature, humidity, air flow or air quality). There are also integrated HVAC systems that can perform multiple functions to control two or more parameters within the IPE. The selection of the HVAC systems will influence space planning, energy use, the number of different systems needed, and the ability to respond to changing conditions in the IPE.

1 Purpose and Scope

1.1 This Engineering Practice sets forth guidelines describing the plant shoot zone environment and the interactions with plants grown indoors without sunlight.

1.2 This Engineering Practice establishes criteria that will promote the cultivation of plants, with a focus on the thermodynamics and air quality of the indoor plant environment.

1.3 The intended audience of this Engineering Practice is the owner and operator of the indoor plant environment (i.e.: “the grower”).

1.4 This Engineering Practice presents design considerations associated with selecting HVAC equipment currently available and commonly used to manage the temperature, humidity, and air quality in the indoor plant environment.

1.5 Excluded from this Engineering Practice are: HVAC systems serving water-cooled LED lighting; HVAC condensate drainage capture, treatment and reuse; thermal storage; and phase change building materials.

2 Normative References

(Reserved)

3 Definitions

A number of these definitions originated from the ASHRAE Terminology online glossary and were modified to apply to this standard. See <https://xp20.ashrae.org/terminology/index.php>.

3.1 abiotic: a non-biological factor affecting the plant health and growth

3.2 adsorption: the process in which molecules from a gas, liquid, or dissolved solid are adhered to a surface by chemical or physical forces

3.3 air distribution: the delivery and movement of air inside the room to manage the environment

3.4 air change per hour (ACH): the number of times the room air is exchanged with the outside air, measured as the ventilation rate (cubic meter per hour, m³/hour or cubic feet per hour, CFH) divided by the room volume (cubic meter, m³ or cubic feet, ft³). A modified form of this calculation is air changes per minute (ACM) based on the air vented in one minute. To convert ACM to ACH, multiply ACM by 60.

3.5 air economizer: the arrangement of duct and dampers with an automatic control system that allows the introduction of outdoor air to reduce the mechanical cooling and/or dehumidification loads

3.6 air throw: horizontal or vertical axis distance an airstream travels after leaving an air outlet before the stream velocity is reduced to a specific terminal value. The rated throw will be a function of a predetermined terminal velocity.

3.7 air turnover rate (ATR): the volume of air that is recirculated through an HVAC system that may or may not include outside air. It is measured as the total supply air compared to the room volume, measured as the number of room volumes per hour (N/h).

3.8 aspirated sensor: a sensor (usually for temperature and humidity) that is placed inside a rigid casing that is shielded from light and ventilated with a small fan to improve measurement accuracy

3.9 biotic: a biological factor affecting the plant health and growth

3.10 Btu: the unit for measuring heat quantity where one Btu is the amount of heat required to raise the temperature of one pound of water by one-degree Fahrenheit. 12,000 Btu/h = 1 ton. 1,000 Btu/h = 1 MBH. 1 watt = 3.413 Btu/h

3.11 envelope: the construction assemblies of a building that are directly exposed to the outdoors.

3.12 condenser: a device that converts refrigerant vapor into liquid by removing heat. Examples include air-cooled, evaporative-cooled and water-cooled condensers.

3.13 condensing unit: a unit consisting of the condenser, one or more positive displacement compressors and motors, condensing coils, liquid receivers, and other devices mounted on a common base

3.14 combined heat and power (CHP): a system that can generate electricity and thermal energy from a single fuel source. These systems burn fuel gas to generate thermal heat that can be used for space or water heating; (they can also be paired with an adsorption chiller to create cooling). This thermal heat is directed into a microturbine to convert into electricity. Some CHP systems can be designed to capture and sequester the carbon dioxide from exhaust gas emissions.

3.15 cooling tower: a heat transfer device that rejects heat to the atmosphere using direct evaporative cooling, typically from a water-cooled chiller or condenser

3.16 dehumidification/dehumidify: the process of removing water vapor from air, also referred to as latent cooling

3.17 desiccant: an absorbent or adsorbent liquid or solid that removes water or water vapor.

3.18 dew point: temperature at which water vapor condenses into liquid water

3.19 direct expansion (DX) system: (1) system in which the cooling effect is obtained directly from the expansion of the liquid refrigerant into a vapor. (2) common term applied to an air-conditioning system that utilizes the vapor-compression refrigeration cycle.

3.20 dry bulb temperature: temperature of air measured by a thermometer freely exposed to the air and shielded from radiation and moisture

3.21 enthalpy: the sum of latent and sensible energy in air at constant pressure and volume. Enthalpy is expressed as energy per unit mass of dry air (J/kg_{air} , $\text{Btu/lb}_{\text{air}}$).

3.22 evaporative cooling: an indirect or direct process of evaporating water to cool air. Direct evaporative cooling is an adiabatic process which simultaneously lowers the dry bulb temperature and increases the moisture content of the air. Indirect evaporative cooling is a sensible cooling process, which only lowers the dry bulb temperature without increasing moisture content of the air.

3.23 evapotranspiration: evaporation from wetted surfaces and transpiration from plants

3.24 exfiltration: the uncontrolled escape of air from a room

3.25 heat pump: an all-electric method of transferring heat from one source to another using the refrigeration cycle, which can operate in one direction or in reverse

3.26 humidification/humidify: the process of adding water vapor into air

3.27 infiltration: the uncontrolled introduction of air into a room

3.28 latent cooling load: the energy needed to remove the required amount of water vapor to maintain the air humidity setpoint

3.29 latent energy (latent heat): energy stored or released during a phase change between water vapor, liquid, and solid (ice) that cannot be felt (sensed)

3.30 latent heat of vaporization: the amount of heat needed for liquid water to vaporize into a gas or the amount that is released when water vapor condenses to a liquid. At $27^{\circ}\text{C}/60\%\text{RH}$ ($80^{\circ}\text{F}/60\%\text{RH}$) and sea level, the latent heat of vaporization is approximately 2435 kJ/kg of water ($1,050 \text{ Btu per lb}$ of water)

3.31 liquid desiccant: the use of a hydrophilic solution to absorb/adsorb moisture from an airstream

3.32 moisture removal efficiency (MRE): a ratio of the moisture removed to the amount of energy consumed in kg/kWh (lb/kWh). MRE is used for rating the efficiency of dehumidification equipment.

3.33 moisture fallout: adding more moisture to the airstream than it can absorb during droplet fall resulting in surface water accumulation

3.34 packaged unit: factory-made assemblies of one or more supply fans, cooling coils, and condensing units

3.35 photolysis: a chemical reaction in which target molecules are broken down by photons

3.36 photoperiod: the period during which the IPE receives photons from electric lighting (e.g. lights on)

3.37 psychrometrics: the study of physical and thermodynamic properties of moist air

3.38 radiation: transfer of heat via electromagnetic energy

3.39 regenerator: the section of a liquid desiccant dehumidification system that re-concentrates the liquid desiccant by applying heat to evaporating water into a secondary airstream

3.40 relative humidity (RH): percentage of actual moisture in the air compared to the total moisture capacity at the dry bulb conditions

3.41 root: the part of a plant that attaches it to the ground or to a support, typically underground, conveying water and nourishment to the rest of the plant via numerous branches and fibers

3.42 sensible cooling load: the amount of sensible energy that needs to be removed from the air to maintain the air temperature setpoint

3.43 sensible heating load: the amount of sensible energy that needs to be added to the air to maintain the air temperature setpoint

3.44 sensible energy (sensible heat): energy that, when added to or removed from a substance, results in a measurable change in dry-bulb temperature that can be felt (sensed) in the air

3.45 shoot: the aerial portion of the plant excluding the fruit

3.46 solid desiccant: a solid material that collects and holds water from a liquid or gas

3.47 stomata: the pores in the epidermis of the leaf or stem of a plant that can open and close to transfer gases in and out of the intercellular spaces

3.48 turgidity: the pressure that keeps cells swollen to support the plant's structure

3.49 vapor pressure deficit or vapor pressure difference (VPD): the difference between the vapor pressure inside the leaf and the vapor pressure of the surrounding air

3.50 variable refrigerant flow (VRF) system: an engineered DX multi-split system incorporating at least one variable capacity compressor distributing refrigerant through a piping network to multiple indoor fan coil units

3.51 ventilation: the controlled introduction of outside air

3.52 volatile organic compound (VOC): any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, that vaporizes under normal atmospheric temperature and pressure and will participate in atmospheric photochemical reactions

4 The Indoor Plant Environment (IPE)

The objective of the Indoor Plant Environment (IPE) is to create and maintain optimal conditions for plant growth while maximizing production value. IPEs allow for continuous year-round crop production in a controlled environment that can be maintained independently of external environmental factors, such as weather.

Plants are photosynthetic organisms that process environmental inputs (carbon dioxide, water, and key nutrients) into biomass and oxygen when exposed to light. The process of transporting water through the plant (from the roots, through the phloem and xylem to the leaves, and out the stomata into the atmosphere) is also known as transpiration. This process provides cell turgidity, nutrient delivery, cell cooling, and fulfills the photosynthetic needs of the plant. The exchange of gases between plant and environment occurs through stomata, which open or close based on environmental cues (light, temperature, relative humidity, CO₂, and water availability). During the dark period, plants transpire and respire, releasing carbon dioxide and water vapor into the IPE. The mass exchange between the plant and its environment depends on the IPE's room design, irrigation delivery method and environmental control system/strategy.

IPEs without sunlight rely on electric lighting as the source of photosynthetically active radiation (PAR). The type of lighting has an impact on the energy balance of the leaf and the IPE.

As plants grow and develop in the IPE, their environmental requirements can change, potentially affecting gas exchange, light input demands, the need for water and nutrients, and the energy balance of the plant. This

dynamic nature of plants can induce changes within the IPE and impact the HVAC system performance requirements.

The energy balance of the IPE is maintained by the law of conservation of energy, through the management of the temperature and humidity. Temperature affects photosynthesis and metabolic rates necessary for growth and translocation of nutrients. Humidity is important for controlling plant transpiration and CO₂ uptake rates through the stomata. The plant yield is affected by the temperature; therefore, it is important to maintain the temperature within the limit of the plant's optimal range. When temperature and humidity are not controlled within the limits of the plant's optimal range, several biotic and abiotic deficiencies can occur due to low or high transpiration and stomatal conductance. Some common deficiencies associated with high or low humidity are leaf tip burn, mold growth, plant wilting, and high leaf temperatures.

Vapor pressure deficit (VPD) is a control variable that combines temperature and humidity into a single factor and is used by growers to manage stomatal opening and conductance of moisture and CO₂. For a given temperature, VPD increases as relative humidity decreases. VPD decreases with increasing relative humidity. The VPD target depends on the plant type, irrigation practices, and the lighting source. Although VPD is the primary driver for transpiration, short-term (less than 30 minute) fluctuations in VPD are not expected to negatively affect plant growth and productivity since it takes approximately 30 minutes for plant stomata to fully open or close between photoperiods.

The ability to control the temperature, humidity, and CO₂ concentration within the IPE depends on how those parameters are measured and monitored. The quality and accuracy of the sensor being used combined with its placement and construction (exposed sensor, aspirated sensor, or radiant shielded sensor) will affect how precisely the IPE can be measured.

The readings may not represent the actual conditions due to the quality of sensor. Most commercial temperature sensors have a margin of error of ± 0.25 – 0.5°C (± 0.5 – 1°F), relative humidity $\pm 5\%$ and CO₂ is ± 50 ppm. Relative humidity sensors have a greater margin of error when utilized in conditions below 20% or above 80% RH. Calibration of the sensors should be completed on a regular (yearly) basis.

5 Energy Balance — Sources of Heat Gain and Heat Loss

To manage the temperature and humidity conditions of the IPE, the sources of energy gain and loss must be calculated and balanced using HVAC equipment. There are two primary types of energy that affect the energy balance of the IPE: sensible and latent. Sensible energy affects the dry bulb air temperature, increasing or decreasing with its addition or removal. Latent energy affects the moisture content of the air, increasing or decreasing with its addition or removal. The moisture content of the air is measured by the humidity ratio (or specific humidity). Latent energy also affects the relative humidity for a given dry bulb air temperature.

5.1 External sources External sources of energy gain and loss are driven by the outside environment. The most common external sources of heat transfer are gains and losses through the building envelope, ventilation, and infiltration/exfiltration.

5.2 Envelope. The envelope includes building materials for the walls, roof, floors and fenestration (windows and doors, including skylights). The rate of heat transfer through the envelope depends upon the characteristics of the materials, construction assemblies, and adjacent or surrounding environment (temperature, humidity, sunlight, shading, wind, altitude, and other geographical conditions).

5.2.1 Design considerations. Choosing building materials that reduce heat transfer will generally reduce the sensible energy loads. Insulation with high R-values (resistance to heat transfer) will reduce the amount of sensible heat that is gained in the summer and lost in the winter, thereby reducing the cooling and heating requirements of the HVAC system. To determine the appropriate R-value, consult with a licensed design professional. Likewise, using materials and insulation that are resistant to water vapor will decrease latent energy transfer across the envelope, which can improve environmental controllability, inhibit mold growth, and prevent degradation of the building materials.

These considerations are also true for the partitions that divide rooms. In some cases, it may be desirable to partition rooms using insulated panels which restrict both heat and moisture transfer. Using materials that have been stored improperly, such as wood, may introduce pre-existing sources of contamination such as mold or insects.

5.3 Ventilation. Ventilation can either increase or decrease both the sensible and latent loads, depending on the outdoor conditions and the target IPE temperature and humidity levels.

5.3.1 Design considerations. The local climate will affect the sensible and latent loads associated with ventilation. For example, if the absolute humidity content of the air outside is greater than the inside target, ventilation should be used sparingly. If the humidity level of the outside air is lower than the IPE target humidity level, ventilation could reduce the dehumidification demands of the HVAC system. When ventilation or air economizers are used, it is recommended they be controlled using both dry bulb temperature and relative humidity sensors to control enthalpy and dew point temperature.

If the IPE is using CO₂ enrichment, the introduction of outside air with a lower CO₂ concentration may require a supplemental CO₂ source to maintain the target concentration range. Ventilation may also be considered during the dark period to reduce the CO₂ concentration level while plants are producing CO₂ themselves via respiration.

A design professional should be consulted to determine the impacts of ventilation on the sensible and latent loads and CO₂ concentrations.

See section 11, Air Quality, for more design considerations.

5.4 Infiltration and exfiltration. Common sources of infiltration and exfiltration include cracks in the building, under or around doors and windows, around unsealed equipment curbs and envelope penetrations, etc.

5.5 Internal heat sources. The most common sources of internal sensible heat gains include electric lighting and motors used to operate fans and pumps. Latent energy is generated by plant transpiration and evaporation from wet growing media and surfaces. Additional sources that generate both sensible and latent heat are CO₂ burners and occupants.

5.5.1 Lighting. Electric lighting is the primary source of sensible heat gain inside the IPE. It is designed to provide the necessary spectrum and irradiance of light to grow plants. The most common lamp types include High Intensity Discharge (HID) lamps (e.g., high pressure sodium and metal halide) and Light Emitting Diodes (LED). These two lighting sources generate different quantities of heat inside the IPE, depending on the lamp's efficiency and power supply. The sensible heat generated by power delivery devices — ballasts (HID) and drivers (LED) — must also be accounted for when they are located inside the IPE. Ballasts and drivers may be integrated or remote from the lamps they serve.

5.5.1.1 Design considerations. HID lighting tends to have lower efficiency than LED lighting; therefore, HID lighting tends to generate more sensible heat in the IPE to achieve the same light intensity as LED lighting. Less heat is generated by LED lighting; therefore, the IPE may require less sensible cooling than with HID lighting. When an IPE with HID lighting is retrofitted with LEDs, additional sensible heating may be required to prevent overcooling when using the existing HVAC equipment.

5.5.2 Motors. Electric motors are used to circulate air (fans), irrigate plants (pumps), and mechanize labor practices (automation). When located inside the IPE, they generate sensible heat that may need to be removed by the cooling system.

5.5.2.1 Design considerations. An estimate for sensible heat gain is equal to 100% of the electrical power input to the motor.

5.5.3 Dehumidifiers. Stand-alone dehumidifiers reject sensible energy into the space.

5.5.3.1 Design considerations. The temperature of the air generated by the dehumidifier can be 5.6°C (10°F) higher than the room temperature. Typically, during the photoperiod, the additional sensible gain generated by the standalone dehumidifier needs to be removed by the cooling system. During the dark period this sensible heat generated by the dehumidifiers may reduce the heating system requirements or increase the

cooling requirements. A design professional may need to analyze the loads to determine the best balance of sensible and latent cooling. See section 7 for more design considerations.

5.5.4 Humidification. When water vapor is added to the IPE, it increases the moisture content of the air.

5.5.4.1 Design considerations. See section 9 for design considerations.

5.5.5 CO₂ enrichment. CO₂ burners generate carbon dioxide in the IPE by combusting natural gas or propane. The combustion process generates both sensible and latent energy, which need to be removed through cooling and dehumidification, respectively.

CO₂ enrichment from gas systems with the storage cylinder located outside the space has a negligible effect on the sensible loads.

5.5.5.1 Design considerations. See clause 11.3 for design considerations.

5.5.6 People. There are periods of time when more employees will be inside the space to manage plants, scout for bugs, prune leaves, maintain equipment, or transplant and harvest a crop. Depending on their activity level, people will generate different quantities of sensible and latent energy inside the room. Review the ASHRAE Handbook, *Fundamentals*, chapter titled “Nonresidential Cooling and Heating Load Calculations”, for representative rates at which heat and moisture are given off by human beings in different states of activity.

5.5.7 Thermal mass. Floors, walls, growing media (e.g. soil-filled pots) and the plants themselves can absorb and release sensible heat.

5.5.7.1 Design considerations. Spaces with concrete slabs and walls that do not reflect light can absorb the radiation and, at a later time, release it as convective heat into the IPE. This absorbed and released heat may need to be considered when calculating the sensible load. The use of reflective materials to improve light distribution also reduces adsorption of radiant heat by the interior envelope and other materials inside the IPE. The sensible heat absorbed and released by plants is minimal in IPEs compared to the latent heat released.

5.5.8 Irrigation/Fertigation. Most IPEs use automated irrigation/fertigation systems to provide regularly scheduled feedings to plants grown in a medium which may be covered or have a small surface area relative to the plant. In these cases, the contribution of water vapor to the IPE is small if not negligible. In the case where plants are grown in large pots or raised beds filled with media, the contribution of water vapor can be significant, especially immediately following an irrigation event. Fabric pots are permeable to water vapor and may continue to evaporate water from both the top and sides after an irrigation event. In general, there is no difference in the evaporation potential of nutrient-enriched fertigation water and non-enriched irrigation water.

5.5.8.1 Design considerations. A small amount of water uptake is stored in the plant. The vast majority is transpired. Hand watering, open top water storage reservoirs, and improperly drained production surfaces may add significant moisture to the IPE, increasing the latent load. When sizing the dehumidification system, it may be difficult to account for evaporation from these sources.

5.5.9 Foliar sprays and surface cleaning. Foliar sprays include intermittent application of fertilizers, compost teas, fungicides, pesticides, insecticides, and plant promoters or suppressors that are mixed with water and then sprayed onto the foliage of plants. These applications are typically infrequent, occurring once per week or less, and can create large spikes in water vapor. Steam cleaning and surface cleaning operations that utilize water-based sanitation solutions, if used, will also contribute to sensible and latent heat gain.

5.5.9.1 Design considerations. Following foliar spray applications, additional humidity control may be required to maintain the target room conditions.

5.5.10 Plants. Plant transpiration is the primary source of water vapor in the IPE. Water and nutrients are absorbed by the roots and transported throughout the plant to support plant growth and health. The vapor pressure differences between the leaves and the surrounding air results in transpiration. The plant can control the rate of transpiration through active mechanisms (stomata opening) and growth mechanisms (number of leaves, leaf area, number of stomata, and modification to the plant cuticle). The grower can control the rate of transpiration through environmental management (light irradiance, temperature, relative humidity, VPD, CO₂

concentration and air movement) and crop management (irrigation, pruning and training). The vapor pressure inside the leaf is a function of the leaf temperature at saturation (i.e. approaching 100% RH). The transpiration rate of a plant will result in a reduction of the local temperature at the leaf and an increase in humidity. See Annex A for a psychrometric chart with an example VPD measurement.

Transpiration plays a critical role in the IPE by converting sensible energy into water vapor without changing the energy content of the air, but effectively changing the air temperature and humidity. During this process of evaporative cooling, liquid water absorbs sensible heat from its surroundings until it absorbs enough to vaporize, simultaneously removing sensible energy (cooling) and adding latent energy (humidifying). This amount of energy to change phases between liquid water and water vapor is called the latent heat of vaporization.

5.5.10.1 Design considerations. The rate of transpiration varies based on the plant type, life cycle and size. Plant transpiration rates not only depend on environmental and crop management, but also the availability of water at the root zone, which can vary over time based on irrigation strategies. For plants that are irrigated multiple times during the day, plant transpiration rates may be consistent and predictable throughout the photoperiod. Plants that are irrigated once every 1–2 days may generate a spike in transpiration rates immediately following irrigation, with rates tapering off over time until the next irrigation. High carbon dioxide levels can also slow the rate of transpiration.

There is a time lag between the lighting cycle change and the rate of transpiration. Typically, this lag lasts up to 30 minutes and can affect the IPE air temperature and humidity, depending on the HVAC system response. See section 4 for more design considerations.

5.5.11 Leaf absorption. Plants have the ability to absorb water and other materials through the leaf. Absorption of water vapor by the leaf is typically negligible.

5.5.12 Other heat gains. Warm pipes (hot water or steam pipes), electrical transformers, and electronic devices may contribute to sensible heat gain.

6 Cooling Equipment

Cooling equipment reduces the dry bulb temperature by removing sensible heat. Depending on the system, it may also add or remove latent heat. Latent heat removal (dehumidification) occurs when the cooling coil is at or below the dewpoint temperature, resulting in the removal of moisture through condensation. See section 7 for dehumidification.

Cooling requirements can be met by either moving energy by means of a heat exchanger or by moving mass by exchanging air or water. Various cooling technologies can be used to meet cooling requirements.

6.1 Mechanical cooling. A mechanical cooling system executes a vapor compression refrigeration cycle, which moves energy from one place (inside the IPE) to another (outside of the IPE).

6.1.1 Direct Expansion (DX) Systems. In a vapor-compression refrigeration cycle, the refrigerant removes heat in the evaporator by directly expanding (DX) the entering liquid refrigerant into vapor as it leaves the evaporator. The vapor is then compressed and piped to a condenser where the heat removed by the evaporator and the heat of compression are rejected to another medium so that the gaseous refrigerant is condensed to a liquid. The liquid is then piped to a pressure reducing device/metering device to be supplied to the evaporator. A DX coil can exist either within the IPE with a fan coil unit as a split system or outside of the IPE in a packaged unit where cooled air is supplied to the space through ductwork. Split systems consist of an indoor unit (fan-coil), outdoor unit (condenser, condensing unit, or heat pump) and refrigerant piping (between the indoor unit and outdoor unit). The fan coil unit uses a fan to force air over the DX coil.

6.1.1.1 Design considerations. It is important for the line set to be sized properly. If line sets are too long or undersized, capacity of the condensing unit will be reduced. To achieve the best performance of the equipment it is important to properly charge the equipment with refrigerant per the manufacturer's recommendations.

DX systems are not able to operate under low outdoor air temperatures without a low ambient kit. Most DX systems with air-cooled condensers have means to control head pressure down to about 2°C (35°F). If head pressure is not adequately controlled, the effectiveness of the DX coil is reduced and could result in poor control, reduced performance, or compressor failure. Low ambient kits usually include valves to reduce the usable area of the condenser, receivers, and crankcase heaters.

6.1.2 Variable Refrigerant Flow (VRF). VRF moves refrigerant around a building via refrigerant piping instead of a conventional type system that moves air around via ductwork. An air or water source outdoor unit with a multi-split system requires refrigerant piping distributed to multiple indoor fan coil units.

6.1.2.1 Design considerations. The systems can either use heat pumps (if heating and cooling requirements are non-simultaneous) or heat recovery technology (if simultaneous heating and cooling is required for different zones). When the VRF system must deliver simultaneous heating and cooling to different zones, it is important to select the heat recovery model. VRF systems are well-suited to handle sensible cooling loads and may require supplemental dehumidification equipment to meet the latent demands of the IPE.

6.2 Adiabatic cooling. Adiabatic cooling, also known as evaporative cooling, uses the latent heat of vaporization to cool the air both directly and indirectly. During the process of evaporative cooling, liquid water absorbs energy from its surroundings until it absorbs enough to vaporize, simultaneously cooling and humidifying the air. The adiabatic cooling effect can be used to cool air directly or indirectly. The amount of heat absorbed is dependent on the difference between the dry bulb temperature and wet bulb temperature of the air.

6.2.1 Direct evaporative cooling systems use water that is directly evaporated into the air, usually by forcing air over a wetted media or by spraying water droplets into an airstream.

6.2.2 Indirect evaporative cooling works on the same principal as direct evaporative cooling, lowering the air temperature by evaporation. The difference with an indirect system is a heat exchanger is used to cool the air supply to the IPE without increasing its humidity.

6.2.2.1 Design considerations. The additional pressure drop introduced by adiabatic cooling media or heat exchanger will increase the required fan power. Direct evaporative cooling adds humidity to the IPE.

6.3 Passive cooling. Passive cooling is an energy conservation measure that uses equipment apart from the mechanical cooling system to assist in meeting sensible and latent cooling loads. For example, the use of a mechanical cooling system can be supplemented or reduced by utilizing ventilation that has a lower enthalpy than the IPE. This approach can be achieved through airside economizers, waterside economizers or adiabatic cooling.

6.3.1 Ventilation fans. Fans can provide sensible cooling to the IPE by exchanging indoor air with lower enthalpy outside air. When outdoor conditions are suitable, colder, drier outside air is introduced while warmer, more humid air is exhausted.

6.3.1.1 Design considerations. Ventilation is most useful when the outside air is colder and less humid than the indoor air. The fans can provide positive, negative, or balanced air pressurization for the IPE depending on the use of supply, exhaust, or both fans, respectively. Relying on ventilation alone as a source of cooling and dehumidifying may not work in all climates year-round. The ventilation strategy should be reviewed by a design professional prior to implementation.

6.3.2 Airside economizers. Airside economizers provide sensible cooling to the IPE by exchanging indoor air with lower enthalpy outside air. When outdoor conditions are suitable, colder, drier outside air is introduced while warmer, more humid air is exhausted.

6.3.2.1 Design considerations. If the ventilation air introduced through an airside economizer is colder but more humid than the IPE, it may decrease the sensible cooling requirements but increase the energy required to dehumidify. If colder and very dry air is introduced, the air may need to be humidified. The ventilation control strategy should be reviewed by a design professional.