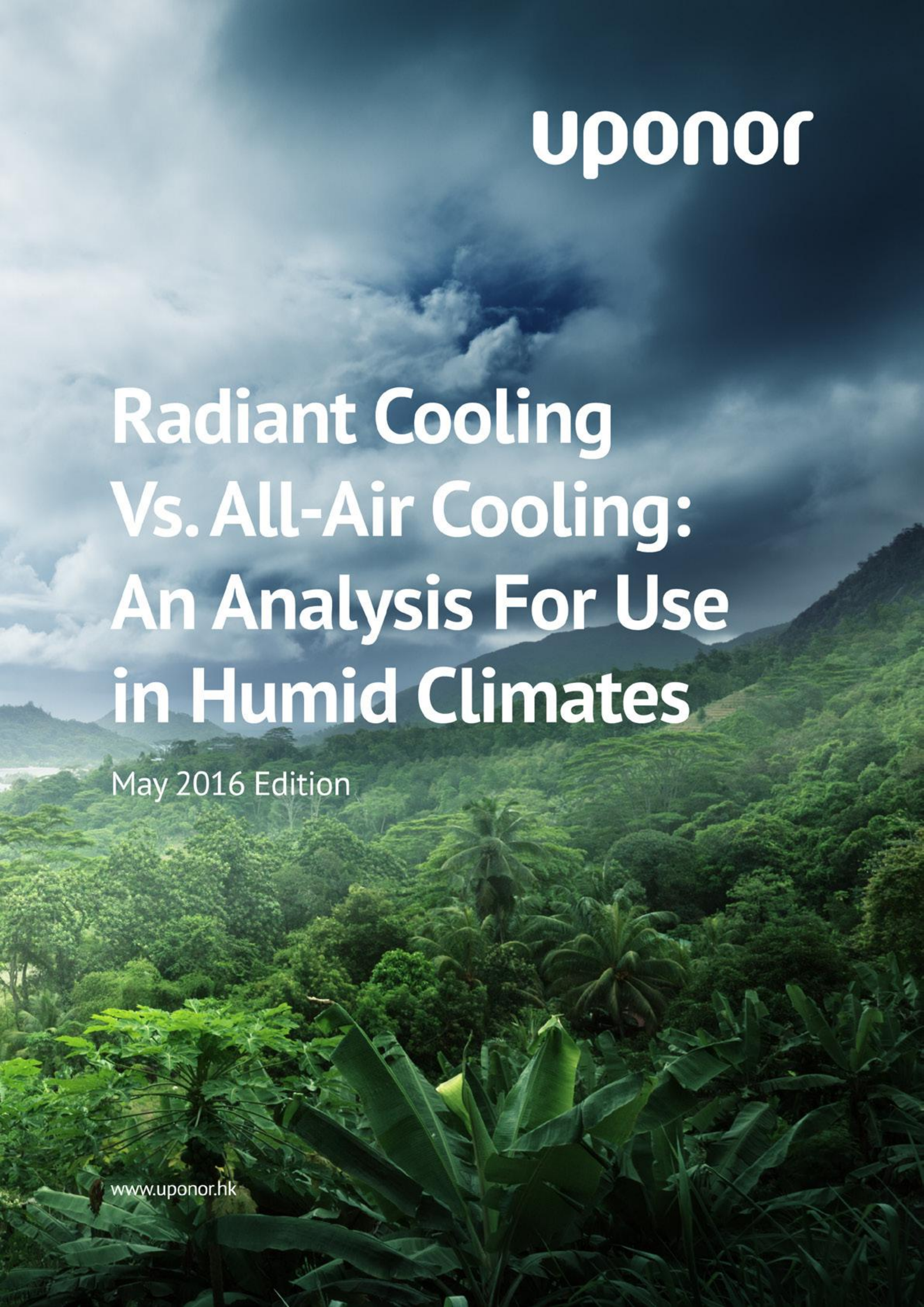

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Radiant Cooling Vs. All-Air Cooling: An Analysis For Use in Humid Climates

May 2016 Edition

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Executive Summary

Architects in regions closer to the equator such as Hong Kong, Singapore and Malaysia are met with the dual challenge of both controlling humidity, and implementing cooling solutions that provide an adequate level of thermal comfort to the building's occupants. Of the solutions currently available, most are familiar with the All-Air systems. However, radiant cooling solutions, as part of Air-and-Water are often overlooked.

The purpose of this eBook is to introduce architects to the advantages and disadvantages of All-Air systems, against that of Air-and-Water systems that employ radiant cooling.

It was found that in comparison for use in commercial buildings in humid climates, when compared to conventional All-Air solutions, Air-and-Water (radiant) solutions are:

- More sustainable and efficient
- More cost effective as a result of ongoing energy savings
- Able to provide greater thermal comfort to occupants
- Able to provide greater architectural freedom due to the reduction in the number of air ducts required compared to All-Air systems
- Able to either dramatically reduce the cost of the building or provide more usable floor space, due to removal of ducts and subsequent decrease in ceiling height

1. All-Air Systems

All-Air Systems

HVAC systems are designed to maintain both indoor air quality and provide thermal space conditioning. Thus traditionally, HVAC systems are designed as All-Air Systems- this means that air is used to perform both tasks.

How do HVAC Systems Work?

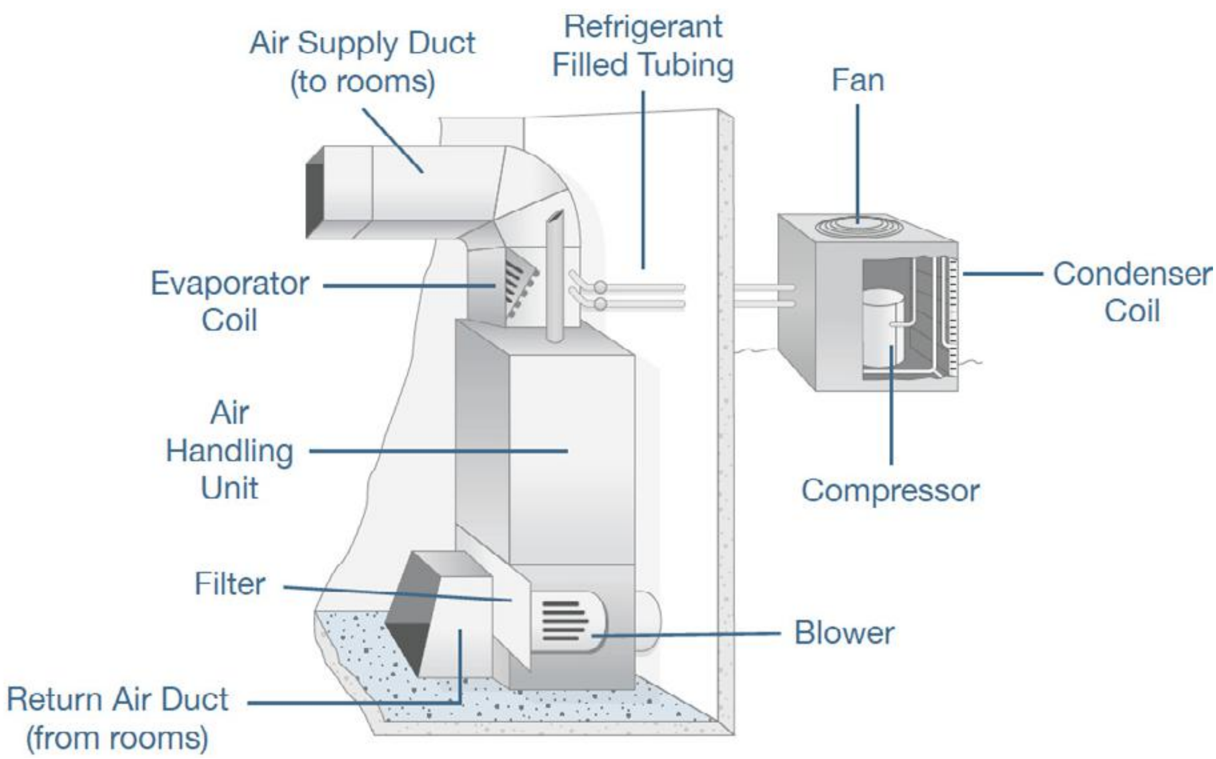


Figure 1

All-Air Power Consumption

Cooling nonresidential buildings contributes significantly to the electrical power consumption and the peak power demand. A significant portion of the electrical energy used to cool buildings is drawn by fans transporting cool air through air ducts.

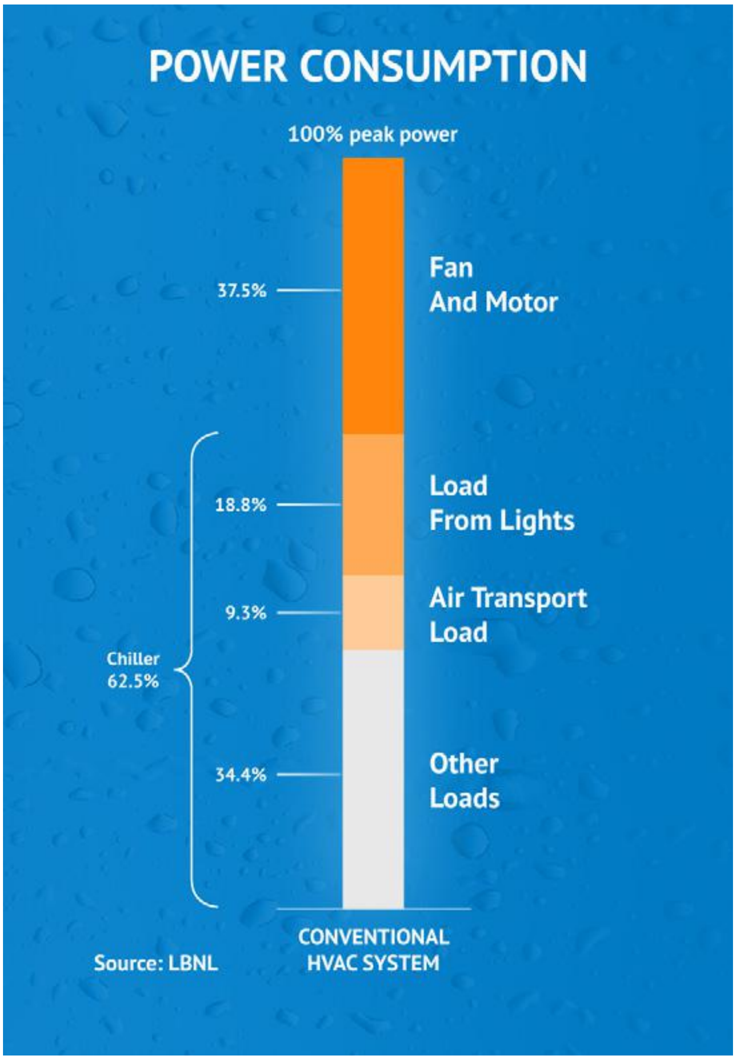


Figure 2

HVAC Systems And Building Design In Humid Climates

Due to the dual purpose nature of All-Air systems they are currently the number one choice in South East Asia for both maintaining indoor air quality and providing thermal space conditioning in commercial buildings.

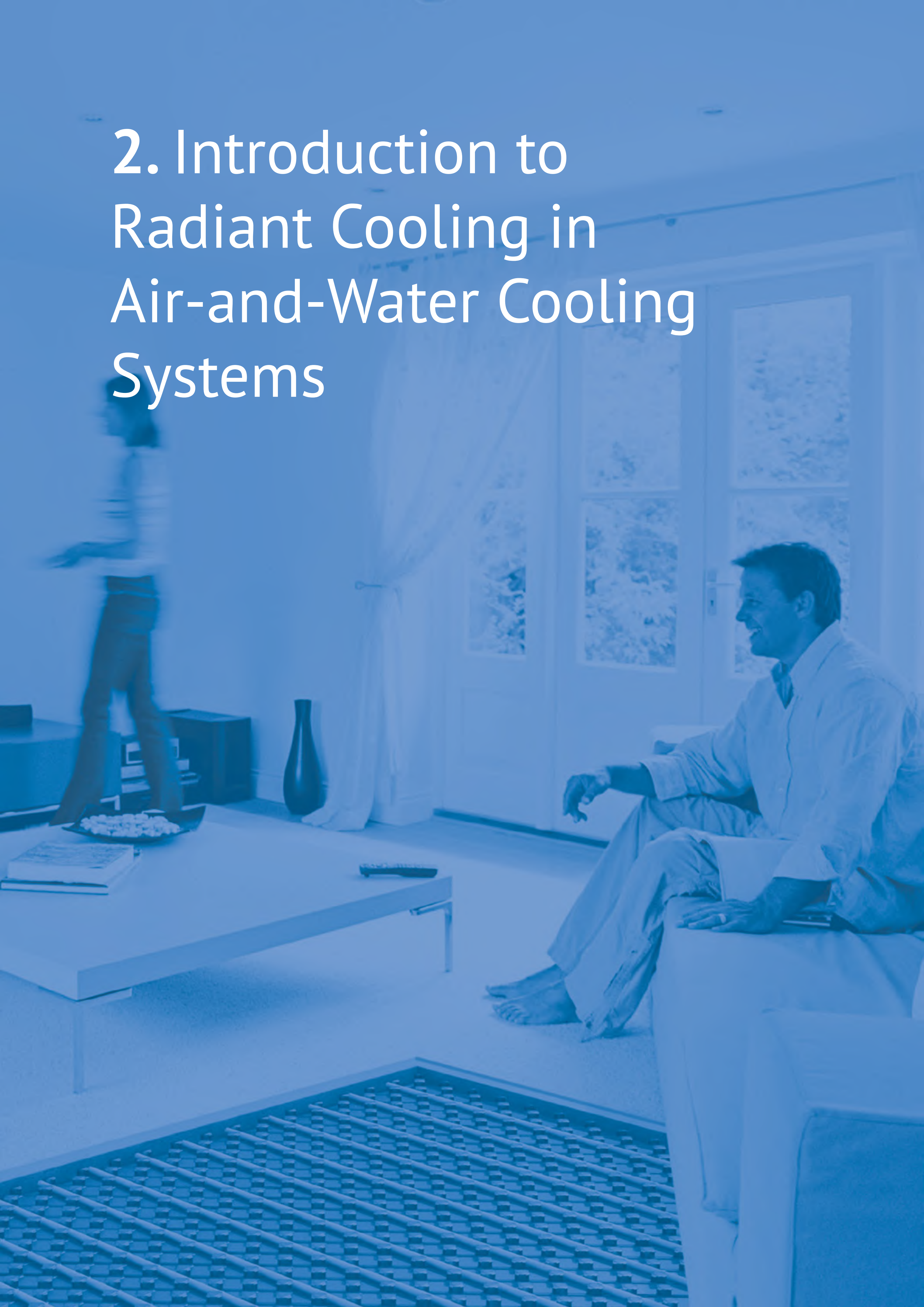
Humidity control

Humidity control is often considered a given when selecting All-air systems, however flawed building and HVAC system designs may fail to maintain proper moisture conditions in humid climates.

Buildings that do not adequately address humidity control are at certain risk of seeing extensive mold growth, an imbalance in the thermal comfort of its occupants and lower indoor air quality. Leading to additional problems including:

- A decrease in overall worker productivity
- An increase in respiratory diseases
- An increase in cases linked to 'sick building syndrome'

2. Introduction to Radiant Cooling in Air-and-Water Cooling Systems



What is Radiant Cooling?

Radiant cooling refers to a temperature-controlled surface that cools the indoor room environment by *removing sensible heat*. Radiant cooling is most effective at removing direct solar heat gain, followed by sensible heat gain.

Figure 3

Radiant cooling systems are hydronic systems that cool the air using circulating water running in pipes embedded in the floor construction of buildings or precast concrete slabs in the walls or in the ceiling. Heat will flow from objects, occupants, equipment and lights in a space to a cooled surface as long as their temperatures are warmer than that of the cooled surface and they are within the line of sight of the cooled surface.

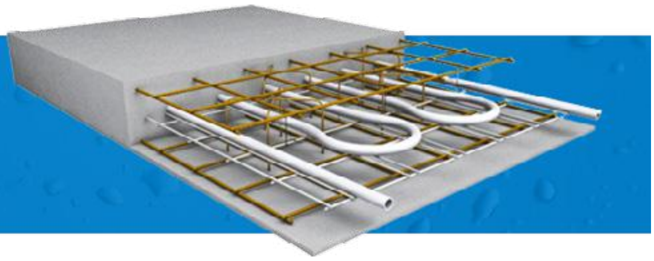
A radiant cooling system operates at warmer temperatures than traditional All-Air cooling systems. Typically, the circulating water only needs to be 2-4°C below the desired indoor air temperature. Once absorbed by the actively cooled surface, heat is removed by water flowing through a hydronic circuit, replacing the warmed water with cooler water.

Air-and-Water Systems

Radiant cooling has no inherent capacity to remove latent heat since it does not dehumidify air. Of course, dehumidifying air is a major consideration in building design in South East Asia. Thus, a hybrid system is required to enable the separation of thermal comfort and ventilation into hydronic and air systems by using:

- The air distribution system to fulfill the ventilation requirements and cover latent loads and remove moisture from the space. In addition, cover any additional sensible loads.
- The water distribution system to thermally condition the space by removing sensible loads through radiant cooling.

Radiant System + DOAS Cooling



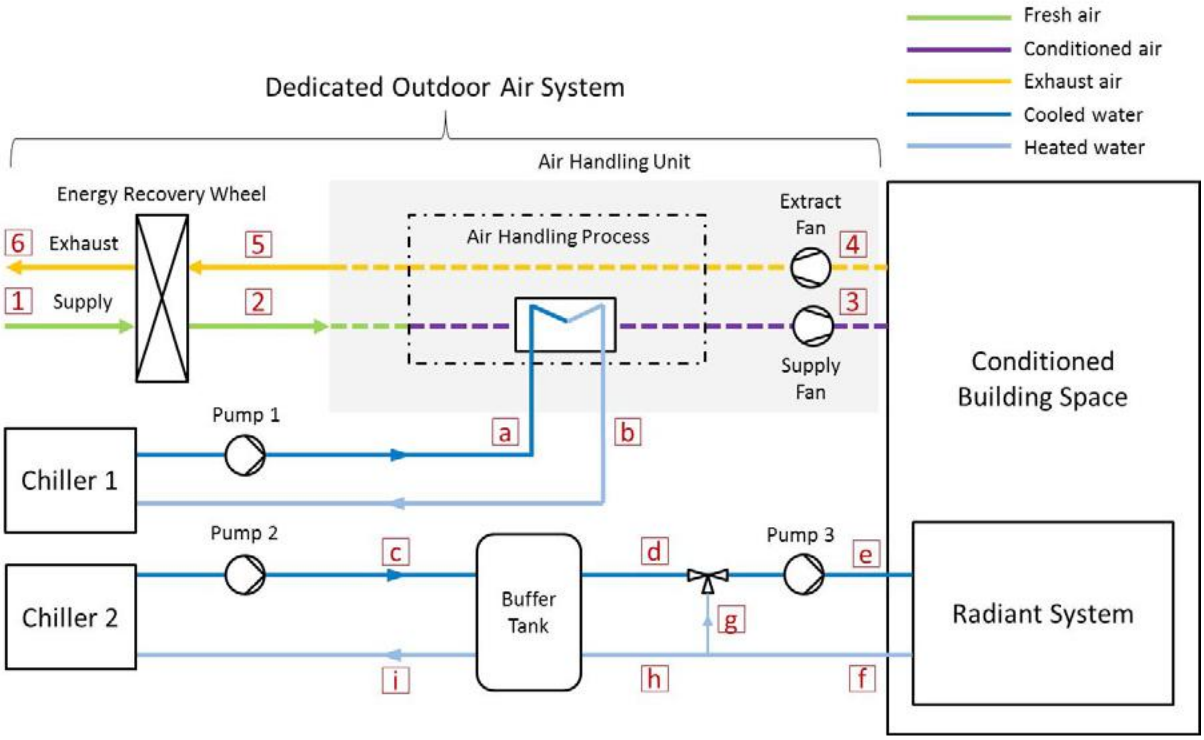


Figure 4

These systems reduce the amount of air transported through buildings significantly, as the ventilation is provided by outside air systems without the recirculating air fraction. The cooling is provided mainly by radiation using water as the transport medium, which is far more efficient than by air due to higher specific capacity.

Due to the separated control of each parameter responsible for thermal comfort, merged in a combined control, thermal comfort and indoor air quality are improved immensely. In short, Air-and-Water systems combines controlled temperature of room surfaces via radiant cooling with central air handling systems.

Air-and-Water System Power Consumption

The radiant cooling system portion of Air-and-Water systems is responsible for thermal conditioning. Due to the physical properties of water, radiant cooling systems can remove a given amount of thermal energy using less than 5% of the otherwise necessary fan energy.

In addition, due to the large surfaces available for heat exchange in radiant cooling systems, the chilled water temperature is close to the ambient temperature and allows to adapt to renewable energy such as heat pumps, injection wells and free cooling by heat exchange to outside air during the night. If standard chillers are used it leads to a better COP.

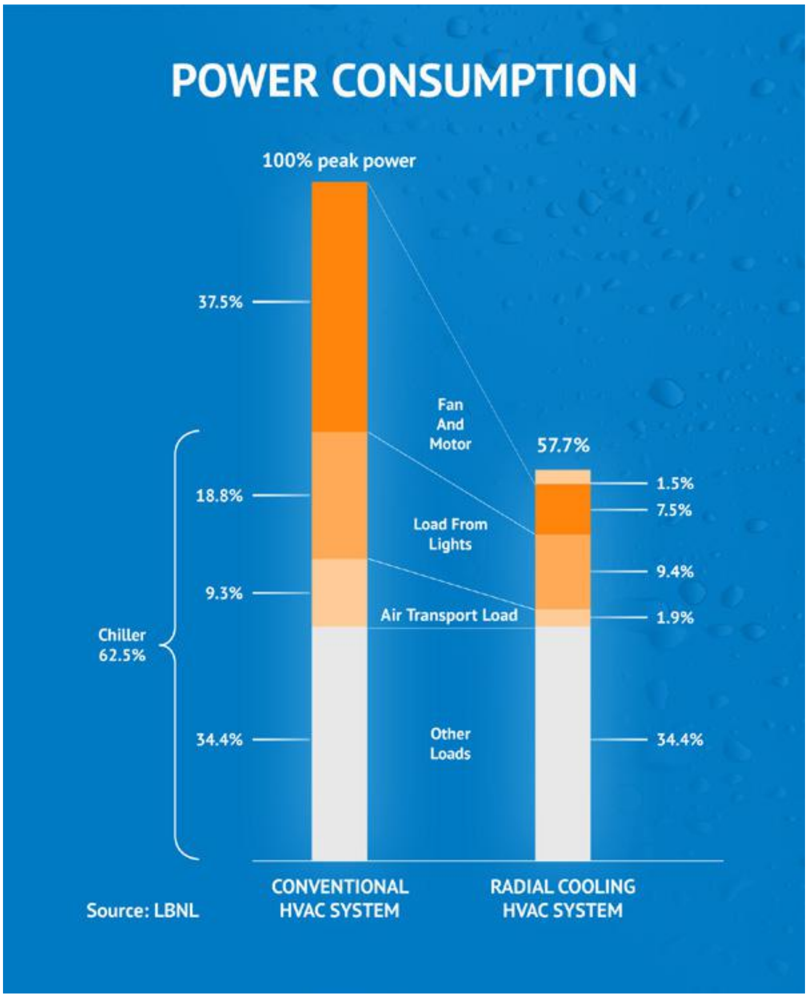


Figure 5

At the same time, radiant cooling systems reduce maintenance compared to All-Air systems, since radiant systems are maintenance free. The ventilation system in combined used with a radiant system in an Air-and-Water system is way smaller and therefore also reduces maintenance cost.

Cooling Power of Radiant Cooling

The cooling power of radiant cooling systems is influenced by different parameters:

1. **The surface temperatures of the cooling elements should be above the dew point of the air in the cooled zone. (The dew point can be manipulated by reducing the air's humidity content easily when employing an Air-and-Water system)**
2. **The effect of the asymmetrical distribution of the radiant temperature comfort. (For offices, ceiling temperatures of approximately 15°C are the lowest limit)**

The table below shows the maximum capacity for radiant heating and cooling different surfaces can achieve at acceptable surface temperatures:

	Total heat exchange coefficient W/m².K		Acceptable surface temperature °C		Maximum capacity W/m²	
	Heating	Cooling	Max. Heating	Min. Cooling	Heating	Cooling
Floor - Perimeter	11	7	35	20	165	42
Floor - Occupied Zone	11	7	29	20	99	42
Wall	8	8	~40	17	160	72
Ceiling	6	11	32	15	72	121

Achieving Ideal Thermal Comfort With Radiant Cooling

Reviewing Thermal Comfort

Thermal comfort is often defined by building scientists and healthcare professionals as, “that condition of mind that expresses satisfaction with the thermal environment”. Now, with this being a condition of the mind, there is clearly room for subjectivity.

In fact, this very notion was outlined in ANSI/ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy which states, “there are large variations, both physiologically and psychologically, from person to person, it is difficult to satisfy everyone in a space. The environmental conditions required for comfort are not the same for everyone.”

Where Does This Leave Us in the Search for Achieving Ideal Thermal Comfort in Buildings?

Thankfully, there are a number of tools such as the **Healthy Heating Comfort Calculator**, based around the ISO7730-1993 standard, and PPD Index that enable building designers to consider the following factors when choosing a method of cooling or heating their building:

- Air temperature
- Radiant temperature
- Relative humidity
- Air velocity
- Activity rate
- Clothing

PPD Index

The PPD (Predicted percentage dissatisfied) establishes a quantitative prediction of the percentage of thermally dissatisfied people i.e. those who felt too cool or too warm. ISO 7730 recommends a target temperature of 22 °C in the winter, and 24.5 °C in the summer.

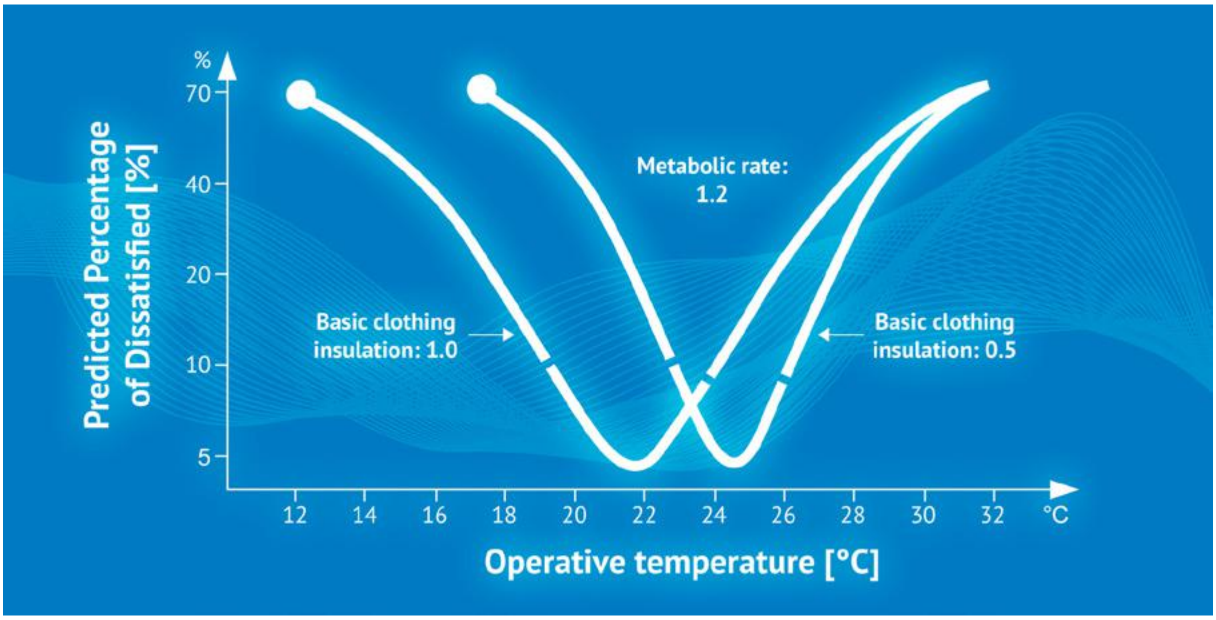


Figure 6

Ideal Vertical Room Temperature

In addition to standard thermal comfort factors, investigations show that the ideal vertical room temperature distribution (allowing for the highest comfort) varies for different cooling systems as shown in the figure below:

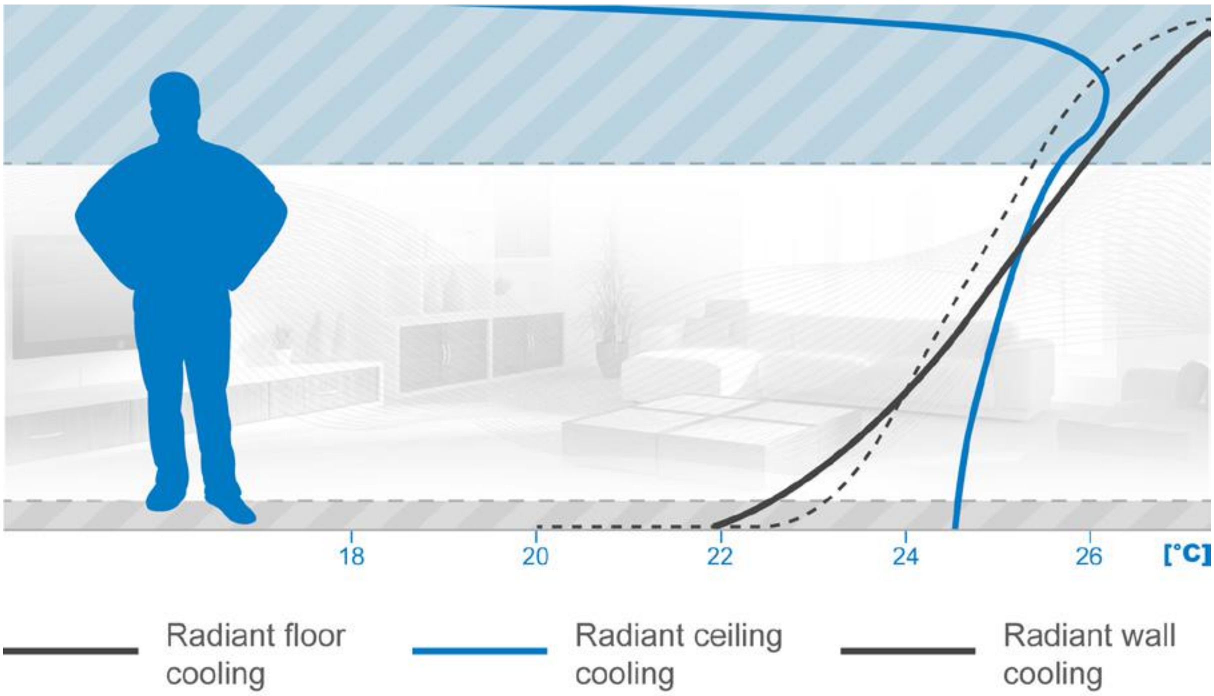


Figure 7

The most acceptable indoor climate is one in which the floor temperature ranges between 22 – 25 °C and the head height temperatures varies from 19 to 20 °C. In other words people feel most comfortable when their feet are a little warmer than their head.

Can PPD be Reduced And Ideal Vertical Temperature Be Maintained With Radiant Cooling Systems?

Using radiant cooling solutions, thermal comfort (even within ideal vertical room temperatures) can be more easily and consistently maintained than through traditional All-Air systems. By optimising the surface temperatures of an occupant's surroundings in a building an even and comfortable environment can be more easily achieved. Whereas in traditional All-Air systems building temperatures are often highly variable in different zones. One important caveat to reduce PPD in South East Asia of course is that radiant cooling is used as part of an Air-and-Water system to ensure adequate ventilation and consistently keep humidity above the dew point.

Humidity & Condensation Control

Condensation can comfortably be managed in Air-and-Water systems. The cooling power of radiative heat exchange is limited by comfortable surface temperature according to standards and by the space dew point. In order to prevent condensation, chilled surfaces in buildings must be kept above the dew point at all operating conditions. Humidity sensors are used to monitor humidity in zones to constantly compensate the supply temperature of the radiant systems according the dew point. Therefore, condensation is not able to occur.

In Air-and-Water systems, to remove high thermal loads by means of radiation, one can manipulate the dew point easily by dehumidifying the supply air. Consequently, the surface temperature of the cooled area can be reduced to increase the operative temperature difference. However, precautions should be taken to keep within the specified comfort limits.

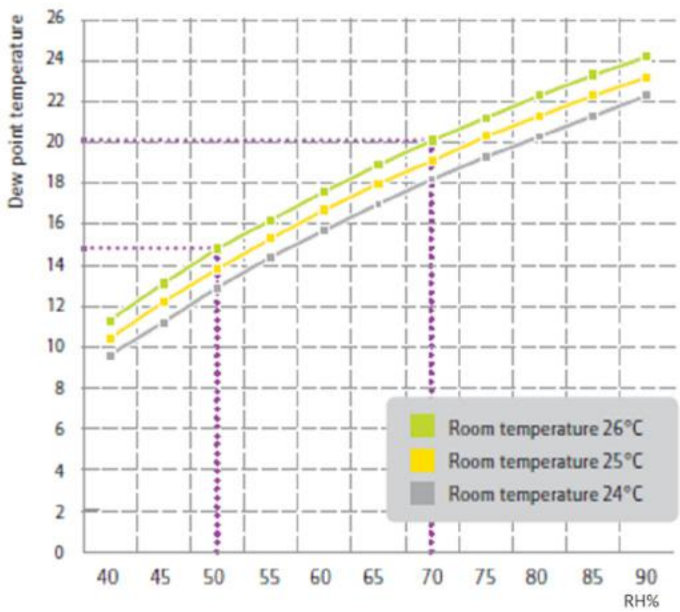
The alternative to reducing the dew point to avoid condensation involves automatically switching off the supply of cold water as soon as the relative humidity reaches excessive levels. In addition, buildings can be equipped with window contacts, cutting off the water supply when windows are opened and the ventilation system cannot guarantee trouble-free operation.

Calculating Required Water Temperatures for Radiant Systems

To calculate the minimum water temperature that can be used, minimum ceiling temperature and dew point must be considered.

Dew point can be calculated with the help of a psychrometric diagram. In order to do this, design indoor temperature (T °C) and relative humidity (RH %) are required.

Minimum and maximum water supply temperature should be calculated taking into account these limits. Where cooling is concerned, the dew point of the water is the limiting factor.



Design conditions:

- Relative humidity: RH=50%
- Room temperature: θ_i=26°C
- Dew point from the diagram: θ_d=15.5°C

Supply water conditions:

- Supply water temperature:
  - θ_v=15.5°C +0.5= 16°C (0.5°C higher than dew point as safety factor for temporary increase in space humidity)
  - ΔT= 4°C
- Return water temperature: θ_r= 16+4=20°C
- Medium water temperature: θ_m= (16+20)/2=18°C

	Cooling	Heating
Maximum radiant temperature asymmetry (EN ISO 7730)	5 K	14 K
Minimum or maximum temperature of the ceiling (EN 15377-1 Annex A)	32°C	7°C

Figure 8, 9, 10

Air Velocity

Air velocity is considerably reduced when employing hybrid Air-and-Water systems. The fact that air is now only used for ventilation and conditioning it's clear to see there will be significantly less draught and significantly lower air velocities.

Revisiting the Healthy Heating Comfort Calculator quantitatively shows the affect air velocity has on PPD. However, a quick walk around any of Hong Kong's (or indeed any other South East Asian cities') busy shopping malls provides a brisk reminder of the discomfort experienced when encountering high velocity, low temperature air in summer clothing.

This is not the case with radiant systems, leading to significantly higher thermal comfort levels experienced by occupants, regardless of the function of the building.

Reaction Time

In addition to thermal comfort factors, reaction times need to be taken into account when considering radiant cooling as a solution. Temperature controls for different radiant cooling systems may have different response times. For example, all systems working within thermal mass (high mass) are relatively slow in response to load changes. If however, operation allows the room temperature to swing and cooling loads can be matched by these systems, they are the most energy efficient systems available.

Systems with water supply close to the cooling surface and with little thermal mass (low mass panel systems) have a response time comparable to All-Air-Systems.

Low Mass Panel Study of Reaction Time

In view of the fact that there are minimum external heat gains / losses in this case, the simulation was run for a two-day period only. The results of the course of the indoor air temperature (ti) and the mean radiant temperature (MRT) during these two days are shown in Figure 5 below . This particular simulation was conducted with a room height of 270 cm and indoor air temperature at 26°C.

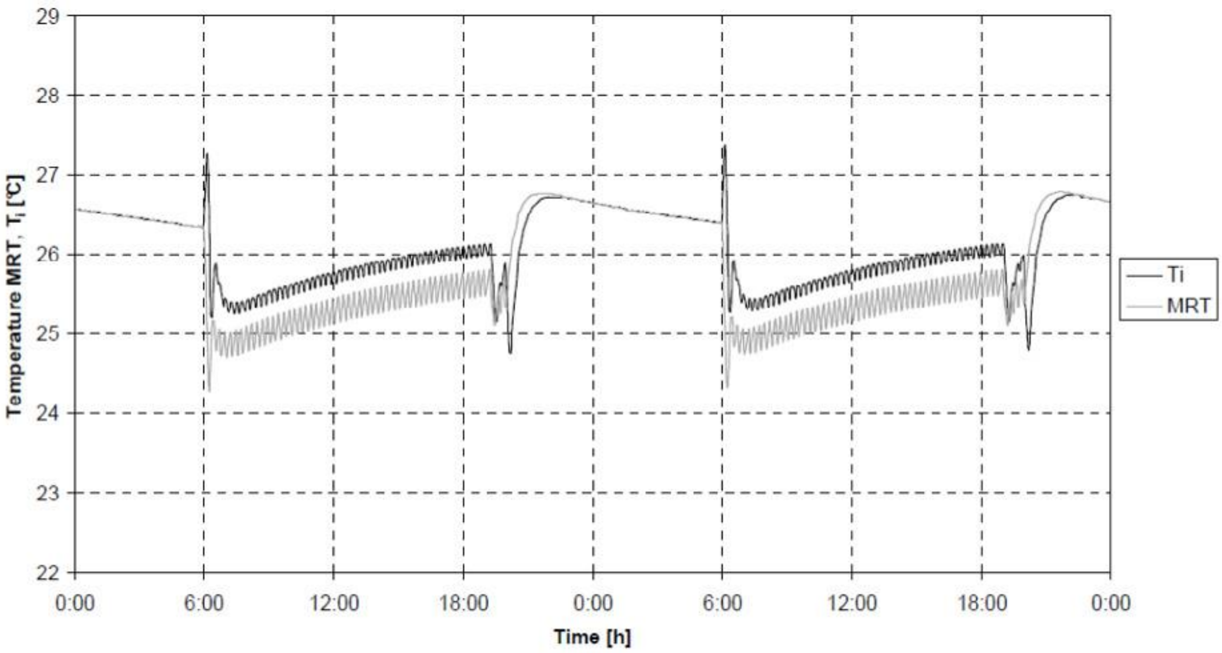


Figure 11: Mean radiant temperature (MRT) and indoor air temperature ti in the middle of the test chamber. The chamber (h = 270cm) is cooled from 6am till 8pm, the required air temperature is 26°C.

The cooling starts later than the effect of heat gains. The consequence is that the indoor air temperature increases at the beginning of the characteristic interval. After that a rapid decrease in air temperature is visible.

Oscillation of ti and MRT values at the end of the characteristic interval is caused by the assumed control procedure. During the night, when the room is not occupied and the cooling system is not active, the indoor air temperature becomes equal to the mean radiant temperature.

From this study we can clearly see that fast response times are achievable when using low mass panel radiant cooling in commercial buildings.

Summary of Radiant Cooling

Features	Effect
Separate ventilation and thermal conditioning	Reduce air movement Improve Comfort
Transport cooling energy by means of water	Reduce transport energy Reduce peak-power requirement
Eliminate recirculation air	Improve Indoor Air Quality
Use large cooling surfaces	Cool at high temperature level
Can utilize alternative cooling sources	Reduce energy consumption Reduce peak-power requirement
Reduce size of thermal distribution system	Improve space usage Reduce building cost
Reduce convection	Improve comfort
Limit cooling output	Need accurate sizing
Increase risk of condensation	Need good humidity control

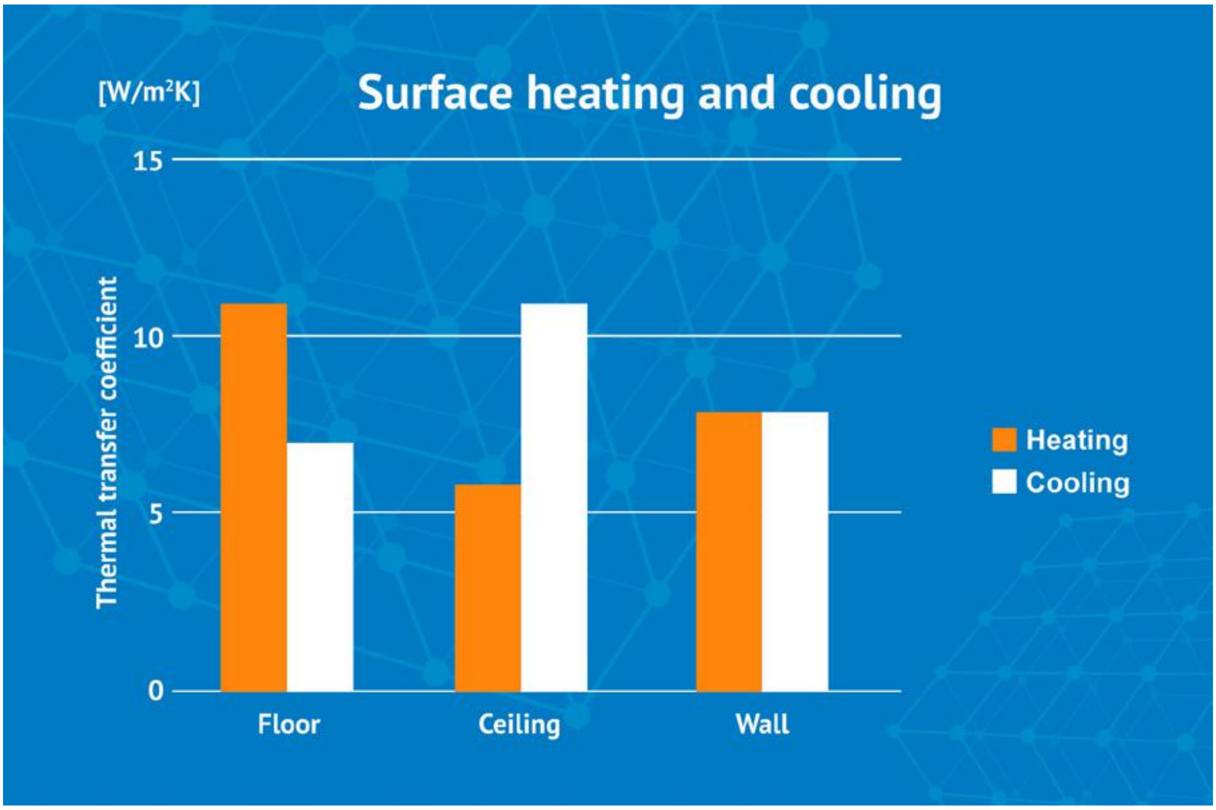
Types of Radiant Cooling Installations and Applications

Thermal Transfer

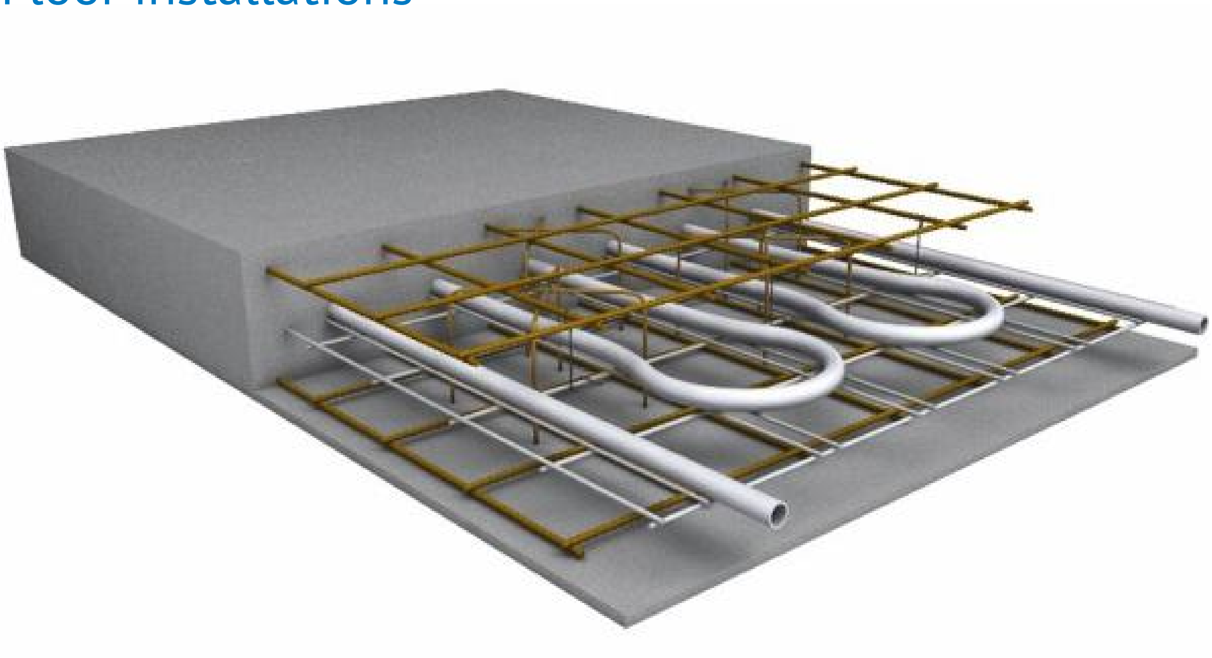
In considering different types of radiant cooling installations, and which ones are required in your building design, one must first consider thermal transfer properties of different surfaces.

The thermal transfer coefficient is an expression of how large an effect per m^2 the surface is able to transfer to the room, per degree of the temperature difference between the surface and the room.

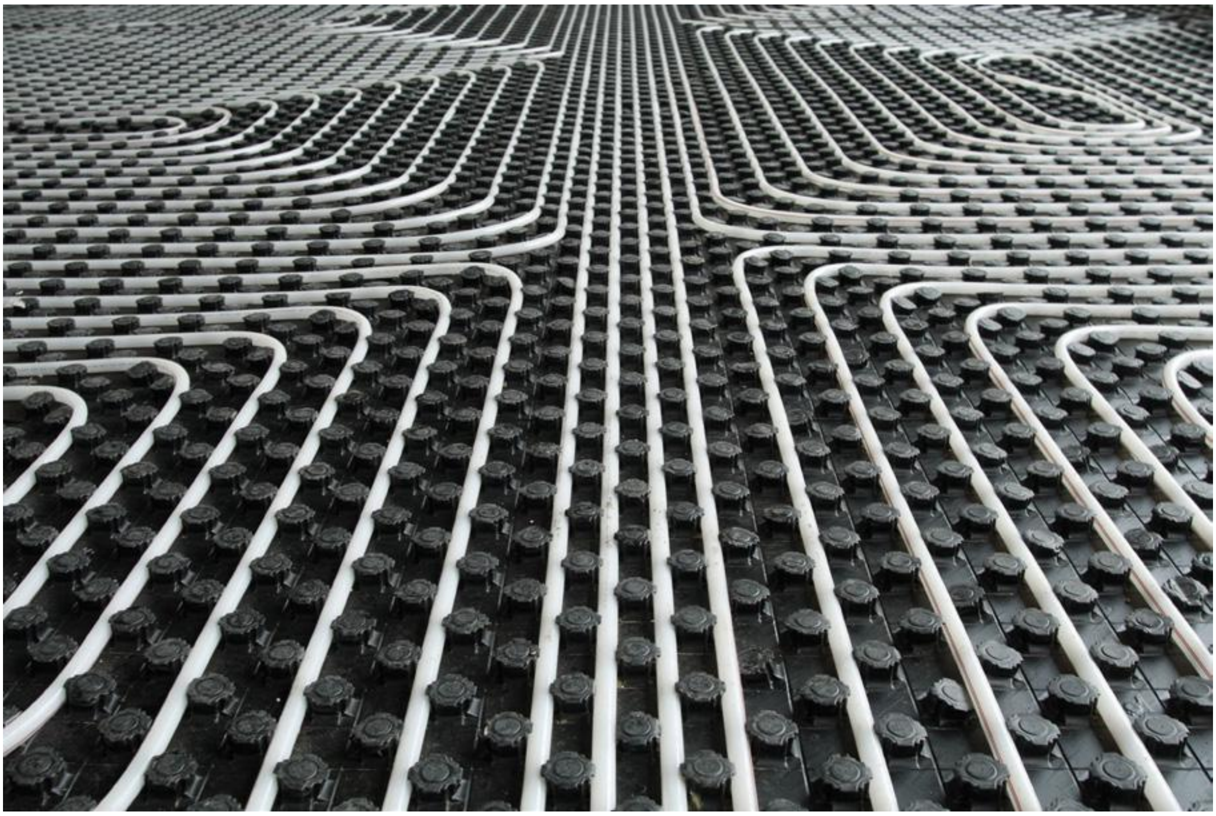
The figure below shows the thermal transfer coefficient for different surfaces for heating and cooling respectively. Due to natural convection, the floor provides the best thermal transfer coefficient for heating while the ceiling provides the best thermal transfer coefficient for cooling.



Floor installations



Water flows through flexible pipes that are laid and embedded in the floor to provide occupants with both cooling and heating options. These pipes are only uni directional, but in thermally active building systems (TABS) pipes laid in precast slabs serve to condition spaces both above and below.



Wall Installations

Pipes with a smaller diameter are embedded in the walls and plastered over. The pipes runs from the same floor circuit, or as a separate circuit.

Ceiling Installations

What Types Of Buildings Can Radiant Cooling Be Used In?

3. Comparing All-Air vs. Air-and-Water Systems for Cooling Commercial Buildings in South East Asia

Aiming for High Performance in Buildings

Today, a high-performance building is seen as a one that uses less energy and exerts a lower impact on our environment, whilst maintaining a high level of human comfort and being more cost-efficient in the long run.

All of these factors (and more) need to be carefully considered when choosing a building cooling solution. In this section we will take a look at how both All-Air and Air-and-Water systems compare in the following key areas:

1. **Sustainability, efficiency & cost**
2. **Architectural freedom**
3. **Ease of installation**

Sustainability, Efficiency & Cost

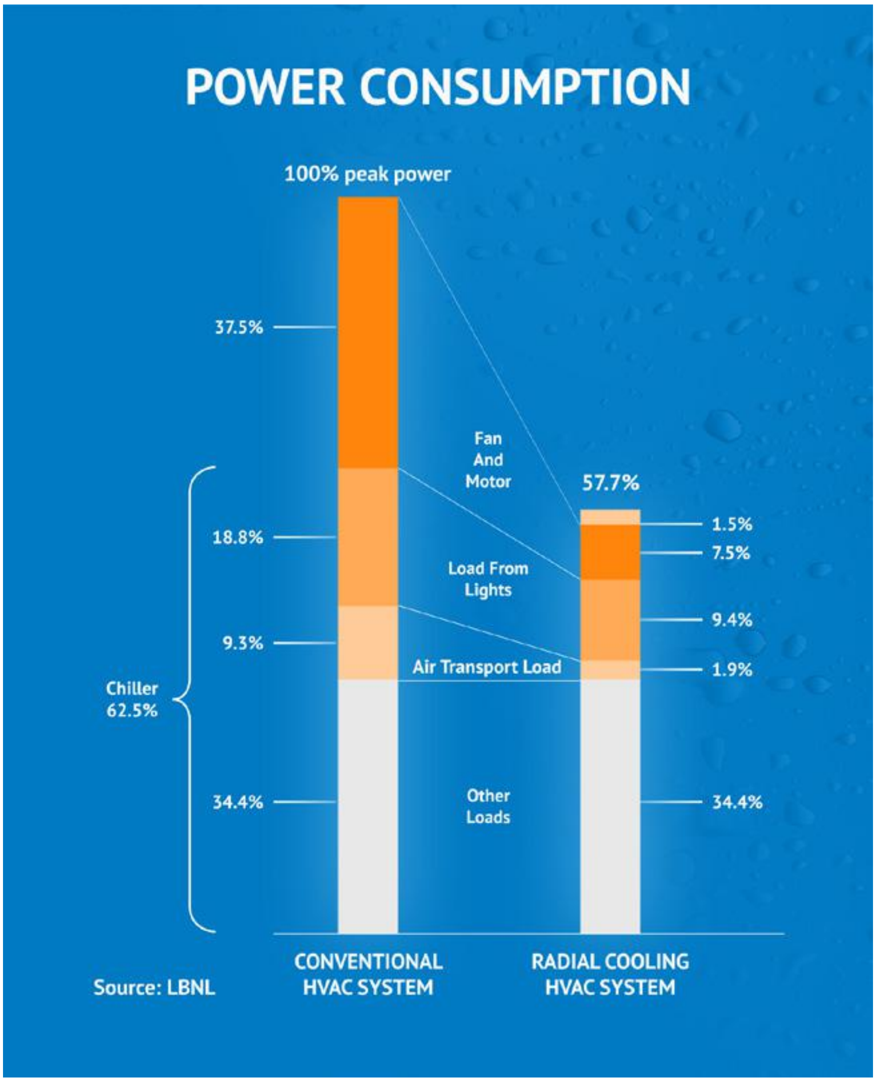
Building sustainability lies at the very heart of all of the factors which contribute to making a building 'green'. Sustainable buildings typically have lower annual costs for energy, water, maintenance, churn and other operating expenses. In addition to this, sustainable building features can promote better health, comfort, well-being, and productivity of building occupants, which can reduce levels of absenteeism and increase productivity.

All-Air Efficiency

All-Air systems are less sustainable and more costly to run in comparison to radiant cooling. This is due to the fact that All-Air systems are powered by an electrical motor or compressors. Considering that a All-Air system typically accounts for around 40% of a commercial building's total energy consumption, the need to downsize its use to cut back on CO2 emissions and make a building greener is paramount.

Air-and-Water Efficiency

Radiant cooling, on the other hand, is a water-powered system that can be used to attain LEED certification in the areas of energy & atmosphere (EA), indoor environmental quality and innovation & design (ID). Owing to the fact that the heat-transfer capacity of water is much higher than that of air, a radiant system that uses a circulator to move water (in lieu of a fan to move air) can achieve the same heat transfer using significantly less energy. By its nature, this type of cooling system is far more sustainable and cheaper to run than traditional All-Air systems.



Architectural Freedom

The freedom to design unique, intelligent structures and bring them to life is an integral part of architectural design. The need to innovate and push beyond what is believed to be possible is driven by architectural freedom, and it is necessary to harness the technology that allows us to do just that.

All-Air Architectural Freedom

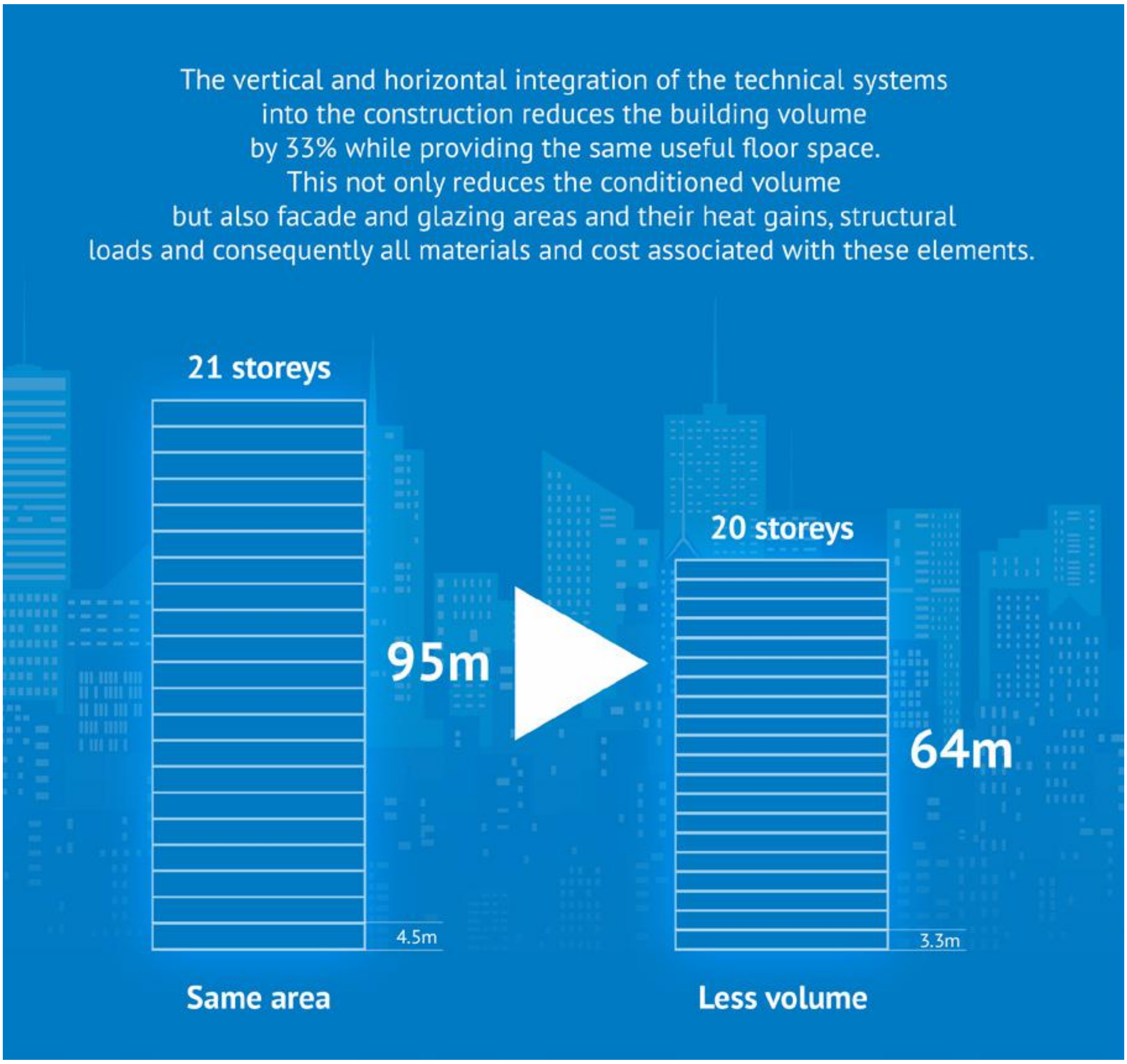
All-Air systems unfortunately do not leave a lot in the way of design creativity. These systems are generally very bulky and come with a network of ducts that not only takes away from the aesthetic value of the building, but also places heavy constraints on space and what is possible from a design perspective.

Air-and-Water Architectural Freedom

A radiant cooling system presents a cooling solution that is invisible to the eye. As the solution is built into the very foundations of the building itself, the volume of ductwork is significantly reduced (if this solution is paired with a dehumidifying system). This leaves architects with additional design space to do as they please.

Additional Floor Space With Radiant Solutions

In new commercial buildings in South East Asia, up to one third of the enclosed volume is occupied by All-Air systems and structural elements, consuming valuable space. Large ceiling plenums are required to accommodate the high volume of ductwork needed for air-based cooling systems, running below deep structural beams.



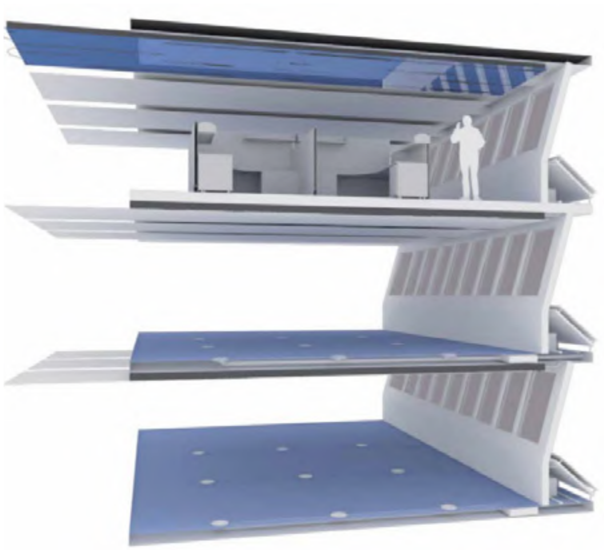
This practice results not only in large floor-to-floor heights that increases the volume of space to be enclosed and conditioned, but also in added material cost, higher structural loads and increased solar and transmission gains from additional façade surface. So, in addition to like-for-like energy and cost reductions, structural designs need to be made that increases spaces and wastes energy to accommodate All-Air systems.

2 Floors

with All-Air Cooling

3 Floors

with Radiant Cooling



Standard All-Air, packaged cooling systems in current use are typically oversized and over-cool the supply air in order to manage humidity levels, resulting in uncomfortable spaces with unnecessarily high energy demand. By switching from All-Air to Air-and-Water based systems, the space required for ventilation systems and their duct work are reduced to about 80% of their original space requirements.

Ease & Cost Of Installation

Bringing a building to life is a massive project that requires a significant amount of time and monetary investment in labor and resources. Selecting a cooling solution that helps one save on both fronts makes the most sense.

All-Air Installation

All-Air systems come with a large amount of heavy equipment and a network of ducts that need to be fitted across the entire building. Installing such a system is a job that requires the coordination of a team of laborers that is possible only once the building envelope has been built. Furthermore, regular maintenance of this system is required to ensure it continues to function properly, adding to the time and resources spent maintaining it.

Air-and-Water Installation

Installation difficulty, time and cost depend on a number of factors in each building. Moreover, whether the building uses either a high (TABS = Concrete Core Activation Radiant system embedded in the core of the structural slab) or low mass installation (chilled ceilings) will impact the installation time, cost and expertise required.

The installation of chilled ceilings is part of the interior fit-out and done after the structure of the building is established. The installation is done by the contractor if the suspended ceiling in combination with the HVAC company responsible for the radiant system. The chilled ceiling systems are provided with a click-in (or push-in technology) and are very fast and reliable.

Radiant cooling solutions providers often work closely with clients, design and engineering teams and provide a nominated design engineer on every project. Thus ensuring existing contractors are able to install radiant systems, and that they are fully supported every step of the way.

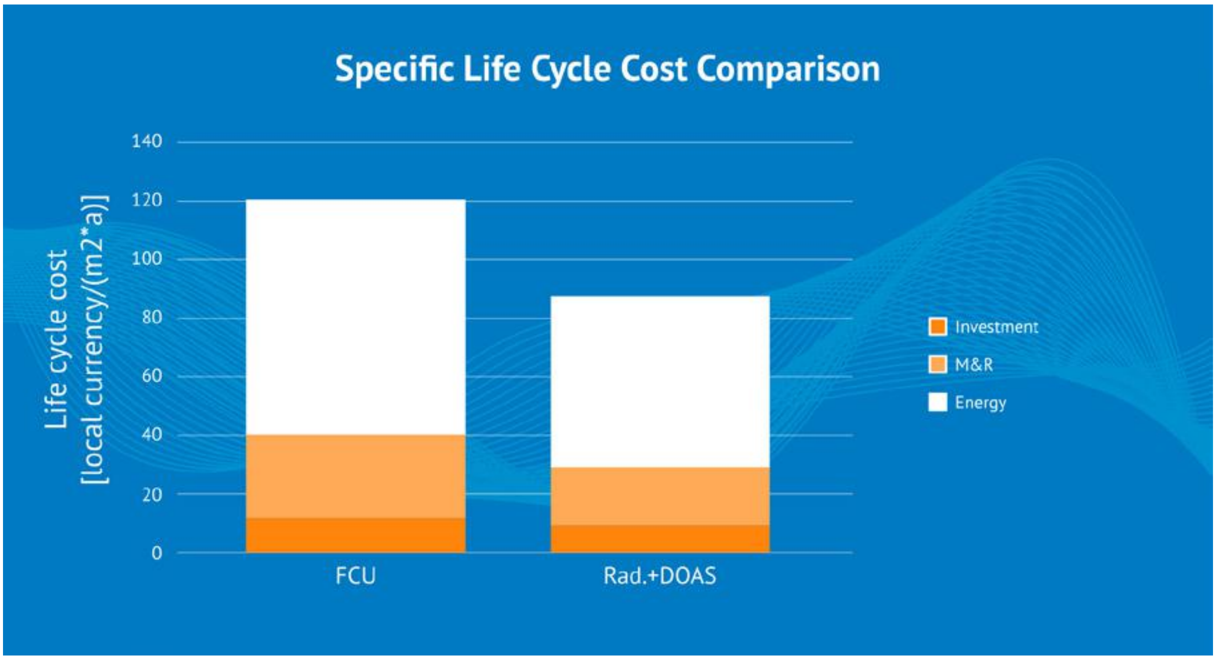
Successful Cases of Air-and-Water Systems in Humid Climates

Malaysia Case Study

In order to fully illustrate how effective Air-and-Water systems can be at both reducing the cost and energy consumption of nonresidential buildings in humid climates, an economic analysis of a 30,525m^2 commercial building in Kota Kinabalu, Malaysia that uses the Uponor 'TABS' system for cooling is presented.

The original fan coil unit (FCU) system & dedicated outdoor air system (DOAS) in the building is compared to the existing radiant system & DOAS are compared to provide a useful benchmark. The DOAS & increased air flow was used to cover all latent loads and higher cooling loads during events. The radiant system was used for base cooling.

Energy Use Comparison		
All electrical		Cooling
FCU (All-Air)	kWh/a	6346004
Radiant + DOAS	kWh/a	4514626



The largest hybrid radiant cooling installation in the world is at the Bangkok International Airport in Thailand, a city where the average relative humidity is between 70-85% year round.

Summary

It was found that whilst the installation costs and times of All-Air systems and Air-and-water systems are often comparable, radiant cooling solutions are:

- More sustainable and efficient
- More cost effective as a result of the ongoing energy savings
- Able to provide higher thermal comfort to occupants
- Able to provide greater architectural freedom due to the reduction in the number of air ducts required compared to All-Air systems
- Able to either dramatically reduce the cost of the building or provide more usable floor space, due to removal of ducts and subsequent decrease in ceiling height

Want Deeper Insights Into How Air-and-Water Systems Can be Used for Commercial Building Cooling in South East Asia?

Uponor's support brochure completes the case for radiant cooling solutions in South East Asia by presenting you with:

- A summary of Air-and-Water systems
- A review of the key areas of radiant cooling use in non-residential buildings
- A closer look at the compelling data behind Uponor's Malaysia case study
- A comprehensive look at Uponor's radiant cooling systems, their benefits and applications
- More information on how Uponor supports your project

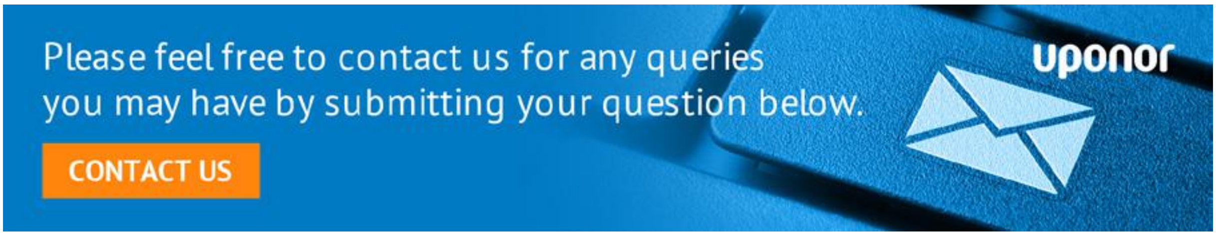
Uponor - The Radiant Cooling Experts

Uponor is a world leading provider of radiant cooling systems. With thousands of projects in service worldwide, we are the experts at designing an effective, energy-efficient solution for any application.

Experienced Team of Commercial Cooling Specialists

Uponor has an experienced team of dedicated professionals in Asia to assist the engineering and architecture community from concept to commissioning:

- Commercial sales representatives provide onsite training and education
- Design engineers provide concept and design support
- Project managers provide project coordination from concept to commissioning
- Inside technical support provides CAD drawings, specifications and submittals



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