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Design for HVAC Optimization

Course Number: AIAPDH252

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HVAC Optimization Final Exam

1. **What does the "A" in HVAC stand for**
   a. Automatic
   b. And
   c. Air
   d. Augmented

2. **What are the two primary issues that HVAC systems address for building users?**
   a. Carbon dioxide (CO_2) extraction and acoustic control.
   b. Air Quality and Comfort
   c. Prestige and Pollution control
   d. All of the above.

3. **_______ is a system used to warn the public when air pollution is dangerous.**
   a. A cell phone
   b. The Department of Energy's Red Zone Alarm
   c. A CO monitor
   d. AQI

4. **What color is an Air Quality Index of 51-100**
   a. Purple
   b. Red
   c. Yellow.
   d. Orange

5. **Which of the following temperatures is not in the zone for a comfortable ambient space:**
    a. 65° C
    b. 19° C
    c. 72° F
    d. 66° F

6. **What 3 factors does indoor air comfort need to manage?**
    a. Cost, noise and appearance
    b. CO emissions, Nitrogen and heat loss
    c. Sunlight, insulation and smells
    d. Temperature, Humidity and Air flow

7. **Prior to modern mechanical HVAC systems, who had the primary role in designing for building air comfort?**
    a. The builder
    b. The local ruler
    c. The Architect or master builder
    d. No one

8. **_________is a traditional cooling architectural element that has been used in areas with severe hot climates.**
    a. Cistern
    b. Windcatcher
    c. Dynamic leaf fan
    d. Refrigerant coil

9. **Most early human settlements and civilizations developed around_________**
    a. Tropical regions
    b. In the northern hemisphere exclusively
    c. The tropic of Capricorn
    d. The southern regions of the tropic of Cancer

10. **Between 1950 and 2018, the world's urban population increased from _______ to _______.**
    a. 20% to 90%
    b. 751 million to 4.2 billion
    c. 237 million to 1.56 billion
    d. 19% to 44%

11. **Which Texas landmark building is referred to as the 8th wonder of the world? _____________.**
    a. The Houston Galleria
    b. Daley Plaza
    c. Cener Pompidou
    d. The Astrodome

12. **Which of the following is one of the variables that are mechanically manipulated in a HVAC system?**
    a. Direction
    b. Materials
    c. Humidity
    d. All of the above

13. **Which is the lowest cost option for residential air conditioning?**
    a. Heat Pump
    b. Window and wall mounted ACs
    c. Furnaces
    d. Central Air

14. **Which of the following is not a component of an HVAC system?**
    a. Solar capture controller
    b. Combustion Chamber
    c. Condenser
    d. Refrigerant Lines

15. What is the type of calculation performed by an HVAC engineer?

a. Net Zero compliance calculation
b. LEED points credit calculation
c. Power utilization analysis
d. The Load calculation

16. One benefit of high ceilings is

a. The keep a space warm.
b. They help make the air cleaner.
c. They prevent the use of air conditioning.
d. They aid in cooling.

17. Can heat from a computer be harnessed to power heating systems?

a. No. This is not conceivable.
b. Yes, but is still in a theoretical stage.
c. No, it was tried and has failed.
d. Yes, it is being used in many buildings globally.

18. According to the author of this course, architects and MEP consultants should strive to move from a sub contract relationship towards one of a ____________

a. Partner
b. An employer-employee
c. A cautious consultant
d. Stay the same.

19. The interior environment factors for sustainable HVAC design are closely linked to which ASHRAE documents.

a. 34-1899 and 43-1961
b. 78-1971 and 66-2323
c. 62-1999 and 55-1992
d. 12-8765 and 2-3168

20. For U-values, which of the following is not true?

a. Higher numbers are good.
b. Lower numbers are good.
c. It is the mathematical reciprocal of the "R" value.
d. It is a measure of heat transfer.

21. Which of the following is a characteristic of a "Smart" HVAC technology as noted in the course?

a. They always eliminate the need for petroleum-based electricity.
b. They are also known as Heat Pumps.
c. They have sensors that "talk" to one another.
d. They are ductless.

22. According to the *worldgbc.org* analysis cited in the course, how much of the of the global carbon emissions come from operational emissions – from energy needed to heat, cool and power buildings?

a. 11%
b. 28%
c. 39%.
d. 0%

23. In a "green building" designed to support NetZero initiatives, which would be the preferred facade for overhangs if the building was located in the southern hemisphere?

a. North
b. South
c. East
d. West

24. **A building type that contributed to the exponential growth of cities like Chicago and New York between 1880-1900 was:**
    a. Concrete frame structures.
    b. The Industrial style.
    c. Rococo.
    d. Skyscrapers.

25. **The first air-conditioned office building was:**
    a. The Sidd Music Hall in Brooklyn, NY.
    b. The Milam Building in San Antonio, TX.
    c. The Galleria in Houston, TX.
    d. The Reliance Building in Chicago, IL.

26. **Air Conditioning has been central to the growth of which of the following cities?**
    a. Dubai, UAE.
    b. St. Louis, MO.
    c. Beijing, China.
    d. Detroit, MI.

27. **According to a 2023 report on KIRO7 new2s station, which city was considered the most air-conditioned in the United States?**
    a. Seattle.
    b. Houston.
    c. Phoenix.
    d. Atlanta.

28. **Who typically generates the Reflected Ceiling Plan (RCP) background?**
    a. The architect.
    b. The MEP engineer.
    c. The Owner.
    d. The Structural engineer.

29. According to the 2013 Australian study cited in the course how much of the total building energy consumption is generally attributed to the HVAC system?

a. 22%

b. 39%

c. 44%

d. 25%.

30. What type of refrigerants were developed to replace the ozone depleting CFCs?

a. Bromine Refrigerants.

b. Feron refrigerants – FFCs

c. Hydrocarbon refrigerants - HFCs

d. Chlorine Refrigerants – CRCs.

31. What is the difference between VRF and VRV systems?

a. VRF regulates refrigerant while VRV regulates air flow.

b. VRF is used in dry climates while VRV is used in humid climates.

c. VRF is used primarily for small residential or light commercial projects while VRV is used in large, complex buildings.

d. They are synonymous terms.

32. An ideal application for a Heat Pump system would be:

a. for commercial buildings in mild to moderate climates, where heating and cooling requirements are relatively balanced throughout the year.

b. for commercial buildings in locations where land is available for the installation of underground loops.

c. office complexes or multi-story residential buildings, where sophisticated temperature control and energy efficiency are essential.

d. for small commercial spaces like offices, retail shops or restaurants in climates with wide shifts in temperature.

33. Which of the following materials is used for HVAC refrigerant lines?

a. PVC.

b. Zinc.

c. Copper.

d. Brass.

34. **Which of the following architectural elements influence HVAC design?**
    a. Building size and perimeter.
    b. Floor to floor heights.
    c. Building insulation.
    d. All of the above.

35. **The greatest amount of air infiltration or loss of heat/cooling occurs from which elements in the building?**
    a. Doors.
    b. Cracks / joints (leaks).
    c. Ceilings.
    d. Windows.

36. **What is the difference between Active and Passive design?**
    a. Active design relies on Solar energy. Passive design relies only on mechanical systems to passively work in the background.
    b. Active design makes use of active building services systems to create comfortable conditions. Passive design maximizes the use of 'natural' sources of heating, cooling and ventilation to create comfortable conditions inside buildings.
    c. Active design requires direct Architectural manipulation of the building façade while Passive design engages the use of an MEP engineer to overcome building design flaws.
    d. Active design requires architectural input while passive design does not require architectural input.

37. **Low floor to floor heights are good for:**
    a. Heating.
    b. Cooling.
    c. Humidity control.
    d. Tropical climates.

38. **Which of the following innovations is not new but has only caught on recently?**
    a. Ice powered Air-Conditioning.
    b. Harnessing heat from a computer.
    c. Geothermal Heat Pumps.
    d. None of the above.

39. How did architects feel "liberated" by HVAC systems?

a. MEP engineers assumed all liability for building envelope design.
b. They made more money as they had less to design.
c. They could add features to buildings because HVAC systems lowered costs.
d. They felt free to design any form in any orientation without being constrained by environmental factors.

40. Who is credited with inventing the Air-conditioner?

a. Jonathan Trane.
b. Willis Carrier.
c. Andrei Olczak.
d. Rutherford B Hayes.

Design For HVAC Optimization – How Architectural design can support better HVAC design

Course Summary

The advent of HVAC (Heating, Ventilation and Air Conditioning), or more particularly the AC part of it, revolutionized building design and enabled an expansion of populations in climatic and geographic zones previously deemed uncomfortable. The relationship between Architecture and HVAC is deeply integrated. While the evolution of HVAC systems have given tremendous liberty to architects in terms of building orientations, congestion, forms and functionality, it can also be argued that these same systems have made architects less aware of the environment that they are building in and for. The ability of having a mechanical system solve all air circulation and temperature comfort within a building regardless of the design and site considerations has been technologically appealing but also environmentally devastating. This is not an indictment of HVAC systems but of the divergence between good architectural design practice and collaborative design of the HVAC systems. Engineers solve problems given to them. Architects define the problems that need solutions. By giving care to the environmental factors being affected by their design and collaborating with their HVAC consultants, architects can help simplify the problems that HVAC systems must address – thus creating a more ecologically friendly and lower energy footprint HVAC system.

This course is intended to increase awareness among architects and designers about the impact of building design on HVAC systems and how those elements that architects develop can help optimize an HVAC solution.

Course Objectives

The objectives of the course are 4-fold:

1. Explore the importance of temperature and air circulation in the design and development of buildings and examine how these issues have been addressed over time and in various climatic zones around the world.
2. Examine the development of mechanical systems to manage sire circulation and building temperature – the coming of the age of Climate Control by means of HVAC.
3. Understand the relationship between a building design developed by the architect and the process of developing a HVAC system as developed by the mechanical engineer.

4. Outline ways in which architects can become more aware and sensitive to those elements of their designs, material selections and building forms that can help optimize HVAC responses and cumulatively achieve a better environmental response that is more energy efficient and offers better air quality for the building users.

Learning Objectives

- Understand the importance of air circulation and temperature control in a building.
- Identify the basic principles employed to design HVAC systems.
- Become familiar with the aspects of architectural design decisions that influence HVAC design.
- Recognize that HVAC response to a building design has direct environmental implications in terms of emissions, energy utilization and air quality for the users.
- How to make design decisions that can help optimize HVAC design.

Course Structure

The course on Design for HVAC Optimization is a three-part course broken down as follows:

- PART 1 – Introduction to air quality and environmental comfort.
- PART 2 – How HVAC works and responds to building designs.
- PART 3 – Architectural design influence to optimize HVAC.

PART 1 – Introduction to Air Quality and Environmental Comfort

1.1. What is Air Quality and Comfort?

In order to understand the key role that modern HVAC systems play in sustaining and expanding the contemporary built environment, it is necessary to explore what primary issues are addressed by HVAC systems and why these are critical to all building designs.

Anytime a building is designed, it, by definition, encloses space. The enclosed space now has an environment that differs from the surrounding "exterior". The extent to which these two conditions differ can vary significantly depending on the composition of the building envelope, building orientation, time of year and general climate of the area where the building is located. The functional reasons for developing a building can be various but, in all cases, it is an obvious and essential requirement that the spaces within the building are comfortable for the users and the ambient environment is suitable for the optimal performance of the intended uses in the building. This includes proper air quality and comfort for human occupants and also for the equipment and related technologies that are housed in the facility.

In the preceding paragraph, the key considerations are "Air Quality" and "Comfort". These are the core elements that define the building's interior environment. Air quality affects all aspects of a building's interior space – from human occupants to machines and building materials. The environmental comfort refers to the use of the word "comfort" as a noun, meaning "the state of being physically relaxed and free from pain" [1] and is utilized specifically for human occupants. At this point it is useful to define these two central concepts which are at the heart of all HVAC design and interface with Architects.

- Air Quality:

  When air quality is good, the air is clear and contains only small amounts of solid particles and chemical pollutants. Poor air quality, which contains high levels of pollutants, is often hazy and dangerous to health and the environment. Air quality is described according to the Air Quality Index (AQI).[2] The AQI is the system used to warn the public when air pollution is dangerous. The AQI tracks ozone (smog) and particle pollution (tiny particles from smoke, power plants and factories, vehicle exhaust, and other sources), as well as four other widespread air pollutants.[3] The five major pollutants established by the EPA (and regulated by the Clean Air Act) are:

  - ground-level ozone
  - particle pollution (also known as particulate matter, including PM2.5 and PM10)
  - carbon monoxide
  - sulfur dioxide
  - nitrogen dioxide

  The AQI works on a scale from 0 to 500. The higher the AQI value the greater the level of air pollution and risk to health. The AQI as we know it today was issued in 1999 and it's been updated several times since to reflect the latest health-based air quality standards.[4] The EPA issues regular (daily) AQI reports and issues advisories, if necessary, based on a standardized color-coded based system. See table below – source: EPA.

[1] Oxford Learner's Dictionaries
[2] UCAR Center for Science Education: https://scied.ucar.edu/learning-zone/air-quality/what-is-air-quality
[3] American Lung Association: "Air Quality Index"
[4] https://www.airnow.gov/aqi/aqi-basics/using-air-quality-index/

Air Quality Index	Who Needs to be Concerned?	What Should I Do?
Good 0-50	It's a great day to be active outside.	
Moderate 51-100	Some people who may be unusually sensitive to particle pollution.	**Unusually sensitive people:** *Consider reducing* prolonged or heavy exertion. Watch for symptoms such as coughing or shortness of breath. These are signs to take it easier. **Everyone else:** It's a good day to be active outside.
Unhealthy for Sensitive Groups 101-150	Sensitive groups include **people with heart or lung disease, older adults, children and teenagers.**	**Sensitive groups:** *Reduce* prolonged or heavy exertion. It's OK to be active outside, but take more breaks and do less intense activities. Watch for symptoms such as coughing or shortness of breath. **People with asthma** should follow their asthma action plans and keep quick relief medicine handy. **If you have heart disease:** Symptoms such as palpitations, shortness of breath, or unusual fatigue may indicate a serious problem. If you have any of these, contact your heath care provider.
Unhealthy 151 to 200	**Everyone**	**Sensitive groups:** *Avoid* prolonged or heavy exertion. Move activities indoors or reschedule to a time when the air quality is better. **Everyone else:** *Reduce* prolonged or heavy exertion. Take more breaks during all outdoor activities.
Very Unhealthy 201-300	**Everyone**	**Sensitive groups:** *Avoid all* physical activity outdoors. Move activities indoors or reschedule to a time when air quality is better. **Everyone else:** *Avoid* prolonged or heavy exertion. Consider moving activities indoors or rescheduling to a time when air quality is better.
Hazardous 301-500	**Everyone**	**Everyone**: *Avoid all* physical activity outdoors. **Sensitive groups:** Remain indoors and keep activity levels low. Follow tips for keeping particle levels low indoors.

[5]

- Environmental Comfort:

  As the name suggests, environmental comfort is about comfort criteria in the design of the built environment — in particular, in terms of heat, light and sound.[6] For the purpose of this course, the focus being on HVAC, the factor that is most relevant is heat and associated humidity. Air temperature is the most significant ambient factor which affects our spatial temperature and level of comfort. But it is not the only factor involved; air speed, humidity and mean radiant temperature must also be considered.

  The zone for a comfortable ambient space generally ranges from a temperature of 65 F (18° C) to 75° F (24° C). However, this range can vary depending on season and climatic zone. In the United sates, we generally use guidelines provided by The American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc (ASHRAE) when designing for building air comfort. The ASHRAE guidelines consider their recommendations for a majority of building occupants wearing a normal amount of clothing while working at a desk. These guidelines recommend 68°F to 74°F (20°C to 23°C) in the winter and 72° F to 80° F (22° C to 27° C) in the summer.

[5] https://www.epa.gov/pmcourse/patient-exposure-and-air-quality-index

[6] Ong, B.L. 2013. Introduction: Environmental Comfort and Beyond. In Beyond Environmental Comfort, 1-15. Abingdon, Oxon: Routledge.

Note that air temperature is a measure of the heat and typical thermometers measure ambient air heat. However, radiant heat loss or gain is also important. Radiant heat may not be reflected in the air temperature, but is the impact of cold or hot objects in the area.[7]

In addition to temperature, Relative Humidity (RH) is also an important factor in air comfort. RH (expressed as a percent), often just called "humidity", measures water vapor, but RELATIVE to the temperature of the air. In other words, it is a measure of the actual amount of water vapor in the air compared to the total amount of vapor that can exist in the air at its current temperature.[8] The ASHRAE guidelines recommend a relative humidity (RH) of 30 to 60 percent.

The third factor for indoor air comfort is air speed. Again, using ASHRAE guidelines, the suggested air speeds under ANSI/ASHRAE standard 55 is not exceed 0.2 m/s (40 fpm). In some cases, higher speeds may be used to raise the upper temperature limit of the recommended comfort zone.[9]

The foregoing discussion was intended to establish the baseline reasoning for why HVAC plays such a critical role in buildings today. The ranges of comfort are fairly narrow and the factors impacting air quality encompass a broad range of conditions. As can be imagined, depending on where a project is physically located, the outside conditions can vary substantially. The role of the HVAC design is to put in place systems that will transform those exterior conditions into an interior atmosphere that falls within the environmental ambient air "comfort" zones and healthy quality of air.

In achieving the above objective, it is all too easy for an architect to abdicate this responsibility solely to the HVAC mechanical engineer and, sadly, in many cases that has become standard practice. While an HVAC engineer can offer mechanical solutions to almost all challenges with the technologies available in the 21st century, these are not always the most efficient, cost effective or sustainable solutions. The architectural design, orientation, material selections, construction detailing, and facade treatments can greatly influence the systems that an HVAC engineer employs and help reduce the energy and environmental impact of an otherwise supercharged HVAC system.

One of the aims of this course is to remind experienced architects and create awareness among new professionals about the importance of design engagement and collaboration between HVAC engineers and architects from an early stage of design. The objective is to understand how an architect's design can help reduce the "comfort" gap between an exterior and interior environment so that the mechanical solutions are milder and consume lower energy to still help attain the desired comfort and healthy environment for the users.

[7] https://www7.nau.edu/itep/main/eeop/docs/airqlty/AkIAQ_ThermalComfort.pdf
[8] National Weather Service (.gov)
[9] www.ASHRAE.org /Standard 55

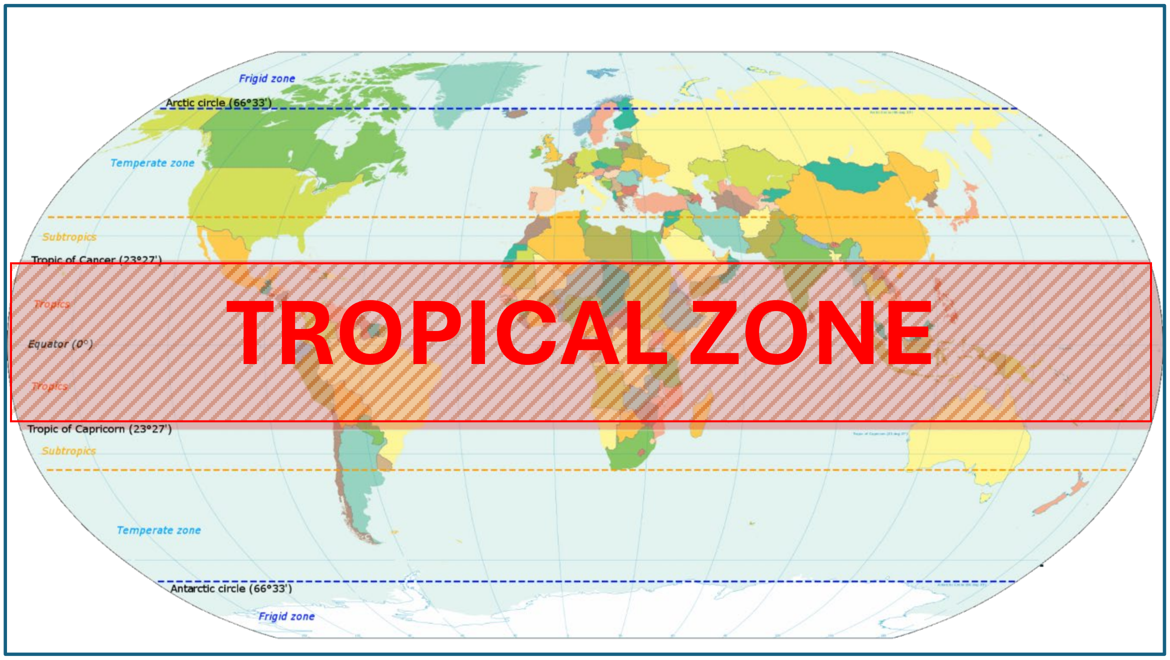
1.2. Historical and Geographical Response.

In the preceding section the primary case for having HVAC systems has been laid out in very basic terms – provide comfortable and safe air for building interiors. It has also been articulated that there is a growing necessity for greater engagement between architects and HVAC engineers to better respond to energy conservation, environmental sustainability and increasing mandates to move towards “green” building designs and NetZero targets. In addressing the latter aspect of increased architectural role in contributing, even if only passively, towards managing building interior temperature, humidity and air quality, one has to start with examining the history of building design methodologies prior to the advent of mechanical systems. The reason for this is simple: Buildings and human usage of them has been a feature of human civilizations for centuries prior to the industrial revolution and its accompanying mechanical advancements. Human comfort parameters were still essentially the same then as they are now. So, the obvious question is how buildings achieved comfort for the users in the past when the only means were architectural elements and design strategies. Understanding these provides a basis to evaluate which are still commonly inherent in contemporary design and which have been abandoned or passed over due to the ease of letting mechanical systems override design inefficiencies (laziness) and climatic challenges.

To understand the way buildings and communities addressed climate challenges for human habitation, we need to break apart the H, V and AC components of HVAC. The reason is simply because H – Heating and V – Ventilation have elicited design responses from the earliest times of human settlement and buildings. The AC component is a relatively recent phenomenon (early 20th century) with widespread adoption in the post-World War II era. We will examine the enormous impact of this in later sections.

Since there is a narrow range of comfort for humans as discussed above, most early human settlements and civilizations tended to develop around the tropical regions of the planet. These are regions of the globe grouped on either side of the equator, lying geographically between the Tropic of Cancer in the Northern Hemisphere at 23°26'10.2" (or 23.43616°) N and the Tropic of Capricorn in the Southern Hemisphere at 23°26'10.2" (or 23.43616°) S. The tropics are also referred to as the tropical zone and the torrid zone.[10] See map below:

[10]https://en.wikipedia.org/wiki/Tropics



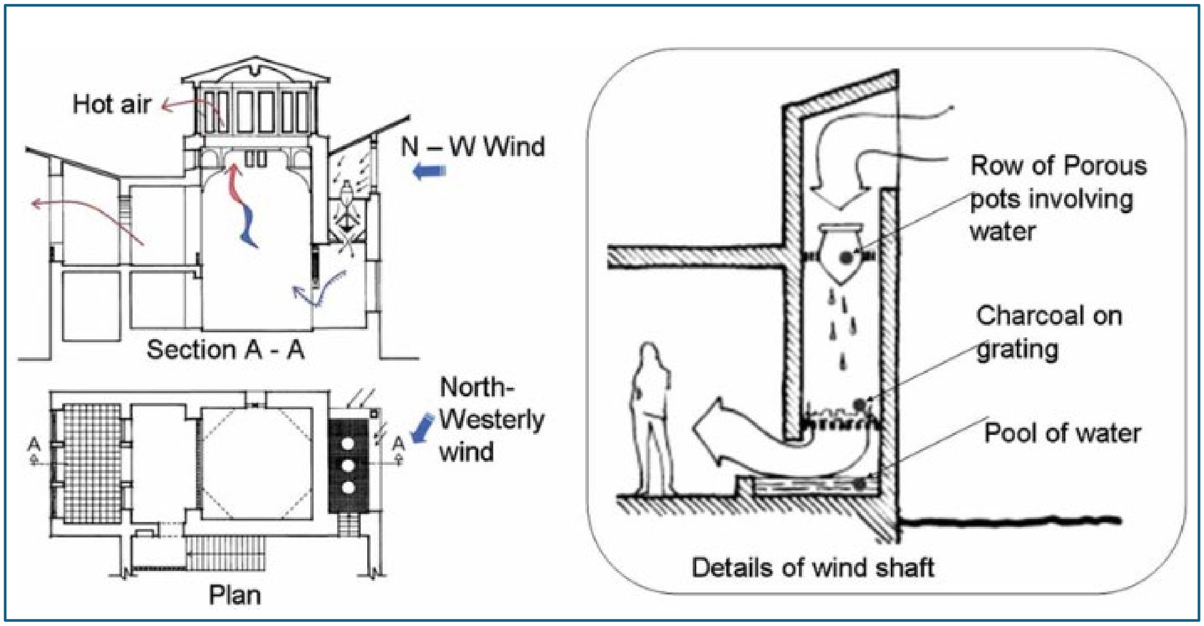
Source: By KVDP - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=27385077 with annotation by author.

The location of the major centers of civilization, whether eastern, western, Asian or Amerindian, was, at least in part, determined by the favorable climatic conditions of these tropical latitudes.[11] The main characteristics of this tropical climate are having an average temperature in every month of above 65°F (18°C). There is no winter season, and annual rainfall is large and exceeds the annual evaporation.[12] These are within or very close to the "comfort zone". As a result, temperature control was basically a non-factor for most of the year and building design focused more on shelter from direct sun, rain and creating paths for air to flow. Wind directions and solar patterns were taken into consideration at least at a rudimentary level. Affluent areas of communities generally evolved upwind of areas with livestock concentrations, avoiding the smell of manure and enjoying more of the fresh air. Poorer sections, as a result, ended up downwind. For individual buildings and homes, the orientation of windows and ventilation openings was determined by wind patterns and enabling cross ventilation to create an internal draft, thereby achieving a gentle air flow. In this way, communities in tropical climates focused mostly on the V (ventilation) part of HVAC. Absence of cold temperatures did not require heating as a design consideration. The brief chilly periods could easily be accommodated by open fires and simply layering on clothing.

[11] https://www.encyclopedie-environnement.org/en/climate/climate-change-and-ancient-civilizations
[12] https://www.sciencedirect.com/topics/earth-and-planetary-sciences/tropical-climate

Beyond areas of tropical climate, as populations expanded, most migratory patterns moved northward since the bulk of the earth's land mass (approx. 68%)[13] is north of the equator and about 75% of that is north of the tropic of Cancer, amounting to about 50% of the total land mass of the planet. A major consequence of these migrations was the need to address cooler climates and a sustained winter season. Geographies also became more varied with deserts, mountains, and semi-arid regions. All of these presented their own challenges for building designs as far as responses for comfort were concerned. While it is not the purpose of this course to explore the many innovative techniques that evolved to meet the various climates and geographies, suffice it to say that the need to heat buildings, at least for part of the year, became essential for continuous human habitation. So, the "H" part of HVAC entered the building design toolkit. For several centuries, stoves, chimneys, and fireplaces were common methods for heating homes and commercial spaces[14] during cold months, while natural ventilation was used for cooling. Buildings were built close together to create density thus trapping heat. Central plazas and terraces were incorporated to facilitate ventilation patterns and provide relief during warmer months. In some desert climates several sophisticated techniques were developed to respond to not only seasons but also dramatic shifts in daily temperatures and the extreme dry climates (low RH). Buildings incorporated porticos around courtyards and with water features to improve relative humidity and the shade of the portico as a device to cool the inner rooms. Some areas developed elaborate design elements to "capture" wind and channel it into the building. A Windcatcher (see diagram below), also known as wind tower, wind scoop, Malqaf, or Badgir, is a traditional cooling architectural element that has been used for thousands of years in countries with severe hot climates.[15]

[13] https://en.wikipedia.org/wiki/Hemispheres_of_Earth
[14] Kingheating.com/blog
[15] Dima Stouhi. "What is a Traditional Windcatcher? " 03 Nov 2021. ArchDaily



Source: Abbas M. Hassan, ResearchGate [16]

A traditional windcatcher is based on a simple technique. Porous pots of water convert dry air into humid air, and charcoal on a grating increases the flow of air into indoor spaces. Here, windcatchers were only used to affect the inside of buildings. [17] Many of these principles are still in active use in many hot and dry regions, mostly in rural areas where traditional vernacular architecture has remained the norm. But these types of elements are increasingly taking on significance as expressions of architectural design. In more recent times, with the increased focus on energy and carbon footprints, has resulted in architects incorporating these types of elements for their original intended purposes – and enhancing their efficiencies with more technological systems and materials. That is the whole point of introducing this example here to demonstrate that architectural design, when properly applied, can and does influence and improve overall comfort of building interiors. Mechanical systems are then used selectively to supplement these systems but at a lower energy utilization.

Similarly, there have historically been many types of vernacular architectural solutions to use passive techniques to provide cooling in hot areas, heating in cool areas, humidification in dry areas and provide dehumidification in humid areas. Some examples to illustrate these techniques:

Passive Cooling:

- Shading devices to limit direct radiant heat.

[16] Hassan, Abbas & Lee, Hyowon & Yoo, Uoosang. (2015). From medieval Cairo to modern Masdar City: Lessons learned through a comparative study. Architectural Science Review. 59. 1-14. 10.1080/00038628.2015.1015947.
[17] ibid

- Wind catchers to redirect ventilation.
- Orientation of windows to enable cross ventilation.
- Use of light colors to reflect heat.
- Use of thick walls for insulation.
- Use of water elements to cool air flow and provide psychological calming.
- High ceilings with high level vents.

Passive Heating (retaining warmth):

- Orientation of windows to maximize direct winter sunlight.
- Use of wall mass to trap heat. In extreme cold climates, ice blocks in igloos act as an insulator, trapping heat. Similarly thick adobe walls in desert climates limit heat transfer during the day and release that heat at night to create warmth during the cool nights.
- Low ceilings to maximize heat retention.

Traditional Humidification:

- Use of water elements to introduce water vapor into the air.
- Manage air flow by use of cross ventilation and introduce a water feature or container to introduce moisture as air moves over it.

Passive Dehumidification:

- Air flow promotes the evaporation of moisture.

As can been deduced from the above, architectural management of ventilation and sunlight has been the traditional means for achieving comfort. In colder climates, heating is supplemented by the use of fire which results in the design of fireplaces and chimneys as both architectural elements and a means of radiating heat to adjacent interior spaces.

These strategies remained the fundamental means to provide comfort for building users for centuries. Where these techniques were not applied or applied poorly, then resulting buildings and communities suffered poor air quality and an unpleasant environment.

1.3. Advent of Mechanical Ventilation and Heating

From around 1760 to the late 1800s, there was a global transition of human economy from an agrarian and manual based system to one that was based on manufacturing and machine-based production. This first industrial revolution was primarily centered in Europe and North America – basically in the economies of the major imperial and colonial powers of the era.

The main features involved in the Industrial Revolution were technological, socioeconomic, and cultural. The technological changes included the following: (1) the use of new basic materials, chiefly iron and steel, (2) the use of new energy sources, including both fuels and motive power, such as coal, the steam engine, electricity, petroleum, and the internal-combustion engine, (3) the invention of new machines, such as the spinning jenny and the power loom that permitted increased production with a smaller expenditure of human energy, (4) a new organization of work known as the factory system, which entailed increased division of labor and specialization of function, (5) important developments in transportation and communication, including the steam locomotive, steamship, automobile, airplane, telegraph, and radio, and (6) the increasing application of science to industry. These technological changes made possible a tremendously increased use of natural resources and the mass production of manufactured goods.[18]

The above changes marked the beginning of the era of artificial heating and mechanical ventilation systems. With the advent of mass production and the rapid growth of factories, air pollution became a major issue and the need to maintain reasonably productive working conditions became a crucial factor. During the early days of the Industrial Revolution, factory conditions were far from ideal. Workers were subjected to long working hours in cramped, poorly ventilated spaces. Factory owners focused solely on maximizing production, ignoring the well-being of their workforce. This resulted in inadequate air quality, high temperatures, and poor ventilation throughout the factories. Workers often faced hazardous conditions, with heat-related illnesses, such as heat strokes and exhaustion, being common.[19] This is where then first mechanical ventilation systems came into being. In the 19th century, steam-powered ventilation systems were developed, revolutionizing large-scale air movement in commercial buildings. The invention of electricity in the late 19th century powered the development of electric fans and motorized ventilation systems.[20] At this point, the mechanical systems started to supplant the need for natural ventilation, wind considerations and other passive air management techniques.

In parallel with ventilation to facilitate better air quality, the need for artificial heating on a large scale became another critical need. Most of the industrial countries were in the northern hemisphere above the tropics and needed heat during the cold winters to keep the factories operational. Coal or wood burning sources were dangerous – both to the labor and also due to the risk of fire for the factories themselves.

One of the first mechanical systems for heating was the use of steam. As early as 1784, James Watt, one of the pioneer engineers of the steam engine, developed a system of heating his home using steam. During the 19th century, systems of steam and later hot-water heating were gradually developed; these used coal-fired central boilers connected to networks of pipes that distributed the heated steam.[21]

However, the first truly popular "central heating" system evolved when Franz San Galli, a Russian businessman, developed an early radiator in 1857. Robert Briggs and Joseph

[18] https://www.britannica.com/money/topic/Industrial-Revolution
[19] https://energy5.com/the-role-of-hvac-systems-in-industrial-revolution-factories
[20] ibid
[21] https://www.britannica.com/technology/steam-heating

Nason pioneered the art of heating buildings by steam and came up with a radiator system using vertical iron tubes in 1863.[22] The modern radiator was thus born.

In the second half of the 19th century, cast iron radiator systems became hugely popular in America. Three manufacturers of those radiators merged to become the American Radiator Company. Radiator based central heating started to fade out by the mid-20th century as combination air-conditioning and heating systems began to take over. However, with the recent emphasis on energy conservation, NetZero goals and general consciousness about the environmental considerations, radiators are making a comeback in some residential and even commercial revitalization projects. In many cases they become the design of choice for their aesthetic appeal with decorative grilles and pipe configurations. In some cases, they are simply an architectural design throwback feature that also solves a heating requirement.

1.4. Climate Control and the Built Environment

As mechanical ventilation and heating systems began to gain popular acceptance, a consequence was that where climate had been a limiting factor in the growth and configuration of the urban built environment, the ability to mechanically control climate became a critical enabler for communities and cities to grow and the development and planning patterns became more influenced by circulation, connectivity and real estate economics rather than natural elements like sunlight, wind directions or ambient temperatures. All these could now be managed artificially. Architects felt free to design any form in any orientation without being constrained by environmental factors. HVAC would inevitably come to the rescue and allow the users to have good indoor air at a comfortable temperature all year round regardless of location. There were several factors that led to a rapid growth of American cities in the latter part of the 19th century, but it is arguable that advances in heating and ventilation were a major contributor. The table below shows the speed of population growth of major industrial cities in America between 1860 and 1900:

Population Growth – Major United States Cities 1860 - 1900			
City	**1860**	**1880**	**1900**
New York	1,174,800	1,912,000	3,437,000
Philadelphia	565,500	847,000	1,294,000
Boston	177,800	363,000	561,000

[22] The Radiator Center: "The History of the Radiator", 7 Dec 2022.

Baltimore	212,400	332,000	509,000
Cincinnati	161,000	255,000	326,000
St. Louis	160,800	350,000	575,000
Chicago	109,000	503,000	1,698,000

Source: Bureau of the Census - as documented in "Urbanization and its challenges" - OpenStaxCollege

Note the dramatic growth of these cities, particularly Chicago which saw an almost 15X growth during this period with the other cities ranging from roughly 200% to 400%. It is not purely coincidental that the developments of Heating and ventilation systems accelerated during this period. Whether these systems promoted growth, or the growth created the demand for mechanical climate control systems is a circular argument. A more plausible explanation is that both developments fed each other. In general, the primary contributors to the massive urbanization are considered to be the following factors:

- Electric lighting and the power grid – the widespread availability of lighting and power made daylight constraints a thing of the past and electric power enabled cheaper and powerful heating and ventilation systems.
- Communications – in the same way that electricity spurred greater factory production and economic growth, the telephone increased business through the more rapid pace of demand. Now, orders could come constantly via telephone, rather than via mail-order. More orders generated greater production, which in turn required still more workers.[23]
- Intracity Transportation – The transition from horse drawn carriages to trolleys and eventually to elevated or underground trains enable people to move quickly across large distances.
- Skyscrapers – As people crowded into cities there was an ever-increasing need for space for factories, offices, residences, and service. For some cities, this meant expansion into surrounding rural areas but for other cities, land, and geographic constraints prevented horizontal growth. Planners had to look upwards. While the means to engineer and construct tall buildings was available, it was not until the invention of the electric elevator in 1889 that skyscrapers began to take over the urban landscape. This is clearly evident in the exponential growth of Chicago and New York from 1880 to 1900. These two cities are considered the birthplace of the modern skyscraper.

The proliferation of skyscrapers created interesting challenges for creating ventilation. As buildings got taller and were built in close proximity to each other, air flow had to be considered when often windows were only on one side of the interior space, making natural

[23] "Urbanization and its challenges" - OpenStaxCollege

cross ventilation impossible. The early ventilation systems, introduced in the 1860s, used steam-powered fans to move air through ducts. After 1890, fans were driven by electricity[24]. Heating was accomplished using radiators.

The systems described in this section continued to define the basic designs of heating and ventilation until the introduction of Air Conditioning (also called AC for short), an invention that completely rewrote the proverbial book on managing air quality and comfort of building interiors.

1.5. Air Conditioning – Facilitating Urban Explosion

In 1902 an American engineer named Willis Carrier was tasked with developing a solution to control humidity at a printing plant in Brooklyn. Carrier designed an apparatus that not only controlled humidity but also cooled the air. His invention, known as the first modern air conditioning unit, featured an intricate system of coils and fans that circulated cooled air through the space. This breakthrough invention formed the basis for Carrier's later innovations and eventually led to the establishment of the Carrier Air Conditioning Company in 1915.[25]

Following the success of the first air conditioning unit, Carrier saw a vast potential for his technology in various industries. Factories, in particular, were struggling with high levels of heat and humidity, which affected both worker productivity and the quality of products. As a result, air conditioning systems were installed in factories, helping to maintain optimal working conditions and significantly improving overall efficiency. The widespread use of air conditioning technology in factories spurred interest in other commercial applications. Theaters soon became one of the early adopters of Carrier's air conditioning systems, leading to the birth of the "summer blockbuster." Before air conditioning, theaters were unbearably hot during the summer months, causing a decline in attendance. By installing air conditioning systems, theaters could maintain a comfortable temperature, attracting more patrons and ultimately changing the course of the film industry.[26]

Air conditioning may have been "invented" in 1902 but it did not immediately gain the almost ubiquitous use that it has today. For example, It wasn't until 1914 that the first residential air conditioner was installed. This groundbreaking unit was an enormous 20 feet long and 7 feet high. It cost $500,000 in 2022 money. In 1931, a comparatively more affordable option was introduced in the form of a window unit. It made air conditioning more commonplace and close to the popularity of today. It resembled modern window units but still came with a hefty price tag.[27]

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[24] "The Skyscraper": digitalhistory.uh.edu ID 3050
[25] Kingheating.com, "The Evolution of HVAC Systems: From the Industrial Era to Today and Beyond"
[26] ibid
[27] https://energyprohvac.com/blog/article/when-did-air-conditioning-become-common; 5 April 2022.

One of the challenges to air conditioning was not technological but cultural, as noted in a Smithsonian Magazine article in 2019: “while Americans had long built fires inside their homes to keep warm for centuries, the idea of a cooling system was a completely different beast. The Smithsonian’s Peter Liebhold says efforts to control one’s environment also raised moral questions.

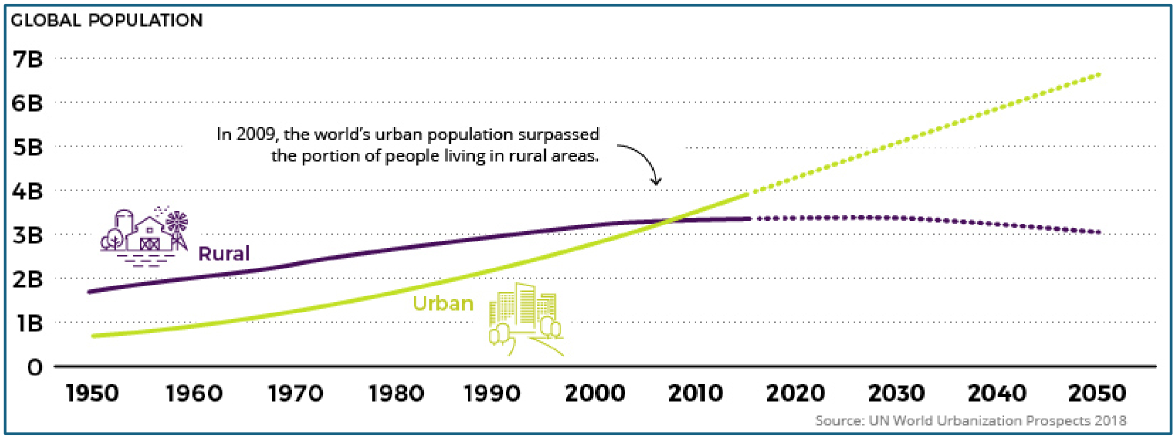
‘There was this notion that trying to control the environment was going against God’s will,’ says Liebhold, a curator in the division of work and industry at the National Museum of American History.”[28]

But Carrier continued to make inroads in commercial applications as discussed earlier. The first air-conditioned office building was the Milam Building, San Antonio, TX, which opened on January 1, 1928. The building was 21 stories high, contained nearly 3 million cubic feet of space, and had 247,779 square feet of gross floor area.[29] Shortly after, skyscrapers began widespread adoption of central air conditioning systems. The systems started to be developed as part of a comprehensive air control mechanism, regulating indoor temperature and humidity. This meant the ability to heat, ventilate and cool using a common system. Thus, the engineering of HVAC was born as it is applied today.

HVAC remained largely a commercial application. It was not until after World War II that the post war prosperity in the United States made air conditioning widely accepted. “The 1950s was a time for keeping up with the Joneses,” says Basile (*Salvatore Basile, author of the book Cool: How Air Conditioning Changed Everything)*. In 1945, Life magazine published a four-page spread about air conditioning, entitled ‘Air Conditioning/ After the War it Will be Cheap Enough to Put in Private Homes.’ The technology was described as a prewar luxury that was being manufactured in large quantities and sold at a moderate cost in the postwar mass market.”[30]

A coincidentally parallel development with the proliferation of air conditioning was the rise in urbanization of the world’s population after 1950. “Since 1950, the world’s urban population has risen almost six-fold, from 751 million to 4.2 billion in 2018.”[31] The graph below illustrates this trend:

[28] SMITHSONIAN magazine; “The Unexpected History of the Air Conditioner”, Haleema Shah, June 24, 2019.
[29] Wikipedia; Milam Building
[30] SMITHSONIAN magazine; “The Unexpected History of the Air Conditioner”, Haleema Shah, June 24, 2019.
[31] https://www.visualcapitalist.com/map-global-rise-of-urbanization; Iman Ghosh, August 23, 2019.



[32]

The most significant way that air conditioning has contributed to this phenomenon is that it made cities with hot or severely dry or humid climates livable and even comfortable. "Cities have boomed in places where, previously, the climate would have held them back. In 1950, 28% of the population of the US lived in its sunbelt, 40% in 2000. The combined population of the Gulf cities went from less than 500,000 before 1950 to 20 million now. Neither the rise of Singapore (and Dubai), nor the exploding cities of China and India (and the Persian Gulf), would have happened in the same way if they had still relied on punkah fans, shady verandas and afternoon nap"[33]

"With air conditioning goes a new kind of architecture, one in which traditional hot-climate devices such as porches, cross-ventilation or pools of water, which create both layers and permeability between inside and out, have given way to sealed boxes. Persian wind-catching towers, or the fountains of the Alhambra, or the humble dogtrot house of the southern US, in which living and cooking quarters are separated by a passage open to the breeze, all proceeded by negotiation between built fabric and the environment. Now it is a matter of technological conquest.

"Building services – their heating, cooling and ventilating systems – came to eat up larger proportions of their total budgets. The people who designed them, services engineers, became influential if underacknowledged officers in the shaping of cities. By the 1980s, buildings such as Richard Rogers' Lloyds building gave formal expression to the ducts and extracts that until then had been hidden. In the Die Hard movies they become a crucial setting of suspense and action, being large enough to accommodate the body of Bruce Willis."[34]

Some architects have even incorporated the HVAC system as a primary design feature of their buildings. The most notable expression of this is the CENTRE POMPIDOU (1977), in

[32] UN World Urbanization Prospect s, 2019
[33] The Guardian; "An inversion of nature: how air conditioning created the modern city"; Rowan Moore, 14 August 2018.
[34] ibid

Paris, France, designed by Richard Rogers and Renzo Piano or the Lloyds Building (1986) in London, England designed by Richard Rogers.

CENTRE POMPIDOU (1977), in Paris, France

Source: https://www.pexels.com/photo/centre-pompidou-combination-of-pipes; Ulrick Trappschuh

The love affair between architects and HVAC systems, whether expressed overtly or hidden in ceilings, walls and floors, was a main catalyst in enabling towns to become cities and cities to morph into megalopolises. The demographics about the rise of "air conditioned" cities tells the story very clearly.

In the 1980s it was undisputed that Houston, Texas was the most air-conditioned city in the world. There was little reason to doubt that without air conditioning and the ability to totally control indoor climate, the city, located in a swampy, hot and humid part of the Texas Gulf coast would have any appeal for becoming the largest city in the state and 4th largest (by population) in the United States. Houston gave birth to air-conditioned marvels like the first covered sports stadium – The Astrodome which at the time was called the 8th wonder of the world!

©Muhammad Siddiqui, 2022

The Astrodome, Houston, Texas (built 1965).The world's first air-conditioned sports stadium – a trend that is now commonplace. Photo: courtesy of the author.

Beyond the Astrodome and maintaining its lead as a city that fully embraced air conditioning, Houston built a large shopping mall with a large ice-skating rink as its focal feature, a feat that would go on to revolutionize the design of shopping malls and inviting radical ideas in other places – ranging from theme parks (Edmonton, Canada) to ski slopes (Dubai). The downtown area of Houston was, and still is, crisscrossed by a vast, air-conditioned system of tunnels so the occupants of the skyscrapers would not have to deal with the natural atmosphere. People can literally leave an air-conditioned home, drive to work in an air-conditioned car, work, meet and eat in air-conditioned buildings, move about the central business district in air-conditioned tunnels and then drive back home – all with never caring for what the outside air was like. Little wonder that Houston grew from just over ½ million in 1950 to almost 5 million in 2010[35]. While AC enabled hot and humid Houston to ignore climate, on the other extreme a similar evolution took place in Alberta, Canada where Calgary has developed a counterpart to Houston's tunnels by creating a series of overhead skywalks connecting its downtown buildings.

[35] https://www.macrotrends.net/cities/23014/houston/population

The Galleria, Houston, Texas (built 1970. Photo: courtesy of the author.

The Calgary Skywalk System, Calgary, Canada (started 1969, ongoing). Photo: courtesy of the author.

The AC enabled metamorphosis of cities was not merely an American trend; it's impact was global.

The 10 largest cities in the world in 1960 were[36]:

1	Tokyo	Japan	16,678,821
2	New York-Newark	United States of America	14,163,521
3	Kinki M.M.A. (Osaka)	Japan	10,614,841
4	London	United Kingdom	8,195,769
5	Paris	France	7,410,735
6	Shanghai	China	6,865,312
7	Buenos Aires	Argentina	6,761,837
8	Los Angeles-Metro	United States of America	6,529,638
9	Chicago	United States of America	6,183,153
10	Moskva (Moscow)	Russian Federation	6,169,961

Almost all are in cooler climates where ventilation and heating were the primary means of maintaining indoor comfort.

By 2020, the distribution of the largest cities had changed[37]:

1	Tokyo	Japan	37,393,129
2	Delhi	India	30,290,936
3	Shanghai	China	27,058,479
4	São Paulo	Brazil	22,043,028
5	Mexico City	Mexico	21,782,378
6	Dhaka	Bangladesh	21,005,860
7	Al-Qahirah (Cairo)	Egypt	20,900,604
8	Beijing	China	20,462,610
9	Mumbai (Bombay)	India	20,411,274
10	Kinki M.M.A. (Osaka)	Japan	19,165,340

[36] https://www.bluemarblecitizen.com › megacities › 1960
[37] ibid

While Tokyo maintains its position as No.1, more warmer climate cities show explosive growth. It would be myopic to suggest that air conditioning was the cause of this as many other economic and social factors were also at play. However, the contribution of HVAC control cannot be dismissed.

Where AC has been central to not only growth but the very survival of the city are some of the following cities which have emerged as key centers of international commerce:

- Houston, Texas
- Dubai, UAE
- Doha, Qatar
- Singapore
- Phoenix, Arizona
- Atlanta, Georgia
- Riyadh, Saudi Arabia

In the United States, Phoenix uses the most AC in the country, followed by Miami, Houston, Atlanta, and Dallas. According to Forbes, Phoenix uses air conditioning more than 75% of the year.[38] Conversely, the least air-conditioned cities were San Francisco, California and Seattle, Washington. The direct relationship between climate and HVAC dependency is clear.

1.6. Redefining Air Quality and Comfort

The net result of the development of HVAC is the ability to climate control the interior spaces of buildings. This capability has helped to redefine both indoor air quality and comfort. This is not to say that the zones of thermal comfort or human sensitivity to air quality have changed but the expectation of the indoor air experience is now expected to conform to a degree of perfection that was not feasible in pre-AC days. The level of tolerance for discomfort is now very low, especially in the more AC dependent spaces. After all, mechanical systems have given the architect the ability to create ski slopes in the sweltering desert or water parks in sub-freezing weather. Sophisticated control systems and zoned thermostats allow people to customize temperature to suite their individual temperament. Architects have become more concerned with forms user functional desires and deferred the management of the indoor air to the HVAC engineer who generally is charged to satisfy the needs without impacting the design of the building. Often this has meant excessive HVAC to overcome the effects of a poorly oriented or improperly insulated building. Whereas architects, at one time harnessed natural elements to inform their designs and maximize passive benefits of nature, with then power of HVAC, those considerations have become inconvenient, and clients are unwilling to pay for the time and effort that it would take to fine tune a design – especially if an HVAC system would still be needed, albeit one with less environmental impact.

[38] KIRO7.com/news: Seattle is no longer the least air-conditioned city in the country; Frank Sumrall, August 17 2023.

This redefinition and shift in architects' design priorities has come with a price in terms of the impact on the environment and proliferation of HVAC systems whether central or applied.

HVAC systems are not magic. They consume energy to run and use refrigerants that produce gaseous emissions. The extra demand on electricity to run HVAC systems requires more generation which in turn emits CO_2 into the atmosphere. The main pollution related impacts of HVAC systems are[39]:

1. ENERGY CONSUMPTION:

   Air conditioning units consume a lot of energy, creating pollution in the form of greenhouse gas emissions. They are referred to as greenhouse gases because they are released into the atmosphere, which in turn causes a planet's warming. These greenhouse gases lead to global warming.

   The excessive use of air conditioners also contributes to the depletion of fossil fuels. Consequently, the demand for more fossil fuels increases, leading to more greenhouse gas emissions. Fossil fuel consumption is also associated with acid rain because many pollutants are released when fossil fuels like coal and oil are burned.

   Air conditioning units tend to be energy hogs because they must work hard to keep the inside temperature cool. They have to use much more energy to balance the difference between the outside and inside temperatures. The amount of energy used by air conditioners varies depending on the size of the unit. This is because larger air conditioners tend to use more energy than smaller units.

2. OZONE DEPLETION:
   Old AC systems should be disposed of properly because they may contain chlorofluorocarbons that can harm the ozone. CFCs are also known as ozone-depleting substances and are used in many air conditioning units. According to the EPA, CFCs are no longer used in new air conditioning units because of their detrimental effects on the stratosphere.
   It has been established that CFCs can be found in many air conditioners and other appliances that use them as coolants. The EPA states that these substances can be harmful to the environment because they deplete ozone content in the atmosphere at a higher rate than they are naturally being replaced by ozone.

3. MATERIALS USED IN AIR CONDITIONING UNITS
   Air conditioning units are made of various materials that may damage the environment. Most of these materials have been used for decades and aren't always recyclable. These materials include copper, fusible metal, plastics, and

[39] Strumheating.com; " 4 WAYS AIR CONDITIONERS MIGHT CAUSE AIR POLLUTION"; Strum Heating and Air Conditioning, June 14, 2022

many other materials. Aluminum and steel are also used in air conditioners that contain substantial amounts of depleting elements such as lead and cadmium. There are a lot of air conditioners that are disposed of improperly. This is because people don't know how to get rid of them. If you live in an area with a disposal collection service, you can give your unit to the collection agency. However, if you don't live in an area with such services, it may be best to dispose of your AC yourself by taking it to a recycling center or by calling the company that made your AC and asking how you can get rid of it properly.

4. UNCLEAN DUCTS
The ducts used to transport the air from the outside to the inside of your home can be a breeding ground for bacteria and mold. Mold is present in most homes and needs to be destroyed. If it is not destroyed correctly, it can spread to other parts of your home. The ducts must be cleaned regularly so that mold doesn't spread to other areas. Although this isn't directly caused by air conditioning, air conditioners increase humidity, making mold easier to grow.

Despite all these concerns, HVAC systems are not the worst offenders in terms of the environment. It can be argued that improper alignment between architects and clients for design objectives creates pressure for over reliance on HVAC systems. As this usage has mushroomed, HVAC designs have also been evolving to make the systems more efficient and environmentally friendly. With the growing concern about global warming and NetZero, architects are also reexamining how they design buildings and interact with their HVAC consultants.

In order for architects to take on a more engaged and collaborative relationship in HVAC design, they first have to understand how HVAC systems work and what factors of building architectural design can have the most meaningful positive influence of reducing HVAC carbon footprint.

The next sections of this course will provide architects with an understanding of how HVAC systems work and how architects and HVAC engineers can collaborate to optimize designs.

This concludes Part 1 of the course.

Part 1 Review Questions

1. Within the AQI index, what numbers are considered Good?
   a. 301-500
   b. 201-300
   c. 101-150
   d. 0-50

2. **Which of the following is considered one of the five major pollutants established by the EPA (and regulated by the Clean Air Act)?**
   a. Carbon monoxide
   b. Nitrogen dioxide
   c. Ground-level ozone
   d. All of the above

3. **The zone for a comfortable ambient space generally ranges from a temperature of ________________.**
   a. 60°F to 85°F
   b. 65°F to 75°F
   c. 63°F to 75°F
   d. None of the above

4. **The ASHRAE guidelines recommend a relative humidity (RH) of ________________ when designing for building air comfort.**
   a. 20 – 40 percent
   b. 30 – 70 percent
   c. 30 – 60 percent
   d. 50 – 70 percent

5. **Which of the following are elements of Passive Cooling?**
   a. Shading devices
   b. Use of light colors to reflect heat
   c. High ceilings
   d. All of the above

6. **Robert Griggs and Joseph Nason pioneered the art of heating buildings by steam and came up with a radiator system using vertical iron tubes in:**
   a. 1843
   b. 1863
   c. 1883
   d. 1903

7. **Which of the following are pollution related effects of HVAC systems?**
   e. Energy consumption – leading to greenhouse gas emissions.
   f. Materials used in Air Conditioning units.
   g. Unclean ducts.
   h. All of the above.

8. **____________________ designed an apparatus that not only controlled humidity but also cooled the air. His invention featured an intricate system of coils and fans that circulated cooled air through the space.**
   a. Franz San Galli
   b. Jospeh Nason
   c. The American Society of Heating, Refrigerating, and Air Conditioning Engineers
   d. Willis Carrier

9. **The first residential air conditioner was installed in what year?**
   a. 1902
   b. 1914
   c. 1931
   d. 1900

10. The main pollution related impacts of HVAC systems is/are:
   a. Ozone Depletion
   b. Energy Consumption
   c. Materials Used in Air Conditioning Units
   d. All of the above

Part 2 of the course will cover:

How HVAC Works and Responds to Building Designs

At the end of this part, you should be able to:

- Differentiate between Heating, Ventilation and Air conditioning.
- Examine the technology and processes behind a functioning HVAC system.
- Understand how an HVAC engineer evaluates a building design – the perimeter shell and the interior spaces and their functions.
- Understand the impact of HVAC on climate change, NetZero and Sustainability concerns.
- Explore passive architectural design considerations relative to site, wind and shade and their influence on HVAC design.

PART 2 – How HVAC Works and Responds to Building Designs

2.1. Difference between Heating, Ventilation and Air Conditioning

HVAC is an acronym that stands for Heating, Ventilation, and Air Conditioning. The term HVAC is used to describe a complete comfort system that can be used to heat, ventilate and/or cool any building interior as well as enhance indoor air quality.

HVAC and air conditioning are often used interchangeably, but the terms refer to two different things. An HVAC system consists of several components that work together to regulate the temperature and ventilation in a building, while air conditioners only cool the building. HVAC systems can include an air conditioner among their components, but a central air conditioner consists of just an air conditioner. Air conditioners fall under the HVAC umbrella, but not all HVAC systems include an air conditioner.[40]

Sometimes the full HVAC system is not required and a subset of H, V or AC is needed. When human occupancy is involved, generally the full HVAC system is best suited to manage indoor air comfort and quality. But there are several building types where human comfort is not the driver but equipment functionality drives the HVAC decision – such as material storage, equipment functionality, content preservation, safety concerns and / or facility life cycle augmentation. Similarly, some industrial processes generate fumes and toxic by-products that need proper exhaust and corresponding make up air.

HEATING: When heating alone is the requirement, the decision is to use heating equipment like space heaters, radiators or spot heating elements can be employed. Heating can be central to warm the entire space, or it can be targeted to heat a selected zone. An example of a building type where only heating is required are equipment shelters or enclosures housing utility systems in sub-freezing temperatures. These will only be required to be heated to ensure that the system remains functional.

VENTILATION: This is the management of air flow through an interior space. All projects have a need for ventilation.

Ventilation systems bring fresh, outdoor air into rooms, filter or disinfect the air there, and improve air flow. Making ventilation system upgrades or improvements in your building can increase the delivery of clean air and reduce potential contaminants in indoor spaces.[41]

Ventilation is achieved by three methods – natural, mechanical and combinations (mixed mode)[42].

1. Natural ventilation – nature's forces drive air into openings and through buildings which have purpose made openings provided to let air invade and escape. This occurs with the aid of wind pressure and stack or buoyancy pressure due to differences between

[40] https://www.usnews.com/360-reviews/services/hvac/what-is-hvac
[41] https://www.cdc.gov
[42] Envirotec.co.uk

indoor and outdoor air temperatures and humidity. Air is forced through buildings, via strategically located openings, due to differences between the condition of the indoor and outdoor air. Openings take the form of doors, windows, chimneys and trickle vents.

2. Mechanical ventilation – electromechanical driven fans are used to move air into, out from and around, a building. Fans are put into ceilings, walls and windows or they are installed into air handling systems that provide air to indoor spaces through air ducts. Separate ducts take air out of spaces to allow the new air into the spaces. Used air, or old air in the space, is mixed with new air with a proportion of old air being extracted. Heavily polluted air is extracted directly from the polluting area using extraction fans. Mechanical ventilation often makes use of pressure. Either creating positive room pressure where air supplied to the room leaks out through openings or negative room pressure where air is sucked out (extract side) by the ventilation system to help draw new air from the system (supply side). Positive and negative pressures are slight in the occupied spaces.

3. Combination or mixed ventilation – mechanical ventilation devices are installed to back up the natural ventilation for when climatic conditions alone are insufficient to provide comfortable habitable and productive workspaces.

In many projects, the primary HVAC function is only to provide ventilation. This is true in many industrial settings where unhealthy or potentially toxic by-products of a process or stored materials need to be ventilated out with constant introduction of fresh air. In other situations, simply providing ventilation at a certain rate can aid in cooling a space if the temperature differential with the exterior is manageable and humidity control is not a major factor. For ventilation, there are three variables that are mechanically manipulated in a HVAC system:

a) Rate – the quantity and quality of outside air brought into the building

b) Distribution – how outside air is delivered to individual rooms and how pollutants are removed

c) Direction – how the air flows in and around the building, from clean to dirty areas

All of the above are managed by ventilation fans, exhaust fans, forcing air flow due to pressure differentials or as part of a more complex forced air HVAC system using end registers or diffuser vents that direct the air out (Supply air) in combination with intake vents (Return) that extract used air. The configuration of the supply and return vents creates the ventilation air flow.

AIR CONDITIONING: Air conditioning, often abbreviated as AC or A/C (US) or air con (UK), is the process of removing heat from an enclosed space to achieve a more comfortable interior environment (sometimes referred to as 'comfort cooling') and in some cases also strictly controlling the humidity of internal air. Air conditioning can be achieved using a mechanical 'air conditioner' or alternatively a variety of other methods, including passive cooling and ventilative cooling.[43]

Air conditioners, which typically use vapor-compression refrigeration, range in size from small units used within vehicles or single rooms to massive units that can cool large buildings. Air source heat pumps, which can be used for heating as well as cooling, are becoming increasingly common in cooler climates.[44]

2.2. Understanding HVAC Systems.

HVAC systems fall into two broad applications – Residential and Commercial. There are some overlaps depending on the building types. For example, high rise residential towers are residential but will likely utilize commercial types of HVAC solutions instead of typical ground based residential units. Likewise, small commercial buildings may employ the same types of HVAC systems that are used in single family residential homes. The decision on which system to use depends on location, budget and the intended use of the system.

It is important that architects understand what type of system will likely be covered depending on the application.

TYPES of HVAC SYSTEMS:

There is no singular HVAC system. Over the years and through numerous innovations and in response to varying climate and building functional requirements, there have developed many permutations of HVAC systems. Understanding the nuances and vagaries of these systems is the proper domain of an HVAC engineer. However, architects should be aware of the major system types and how they function so they can engage in meaningful conversations with their HVAC engineers to help design the best system for their building and collaborate on how the building design itself may help drive to a better, more energy efficient and environmentally friendly solution.

When researching this topic, it was hard to achieve any universal consensus on a single list of how many types of HVAC systems exist. Whether it was consultation with HVAC engineers or online research, the lists varied on whether the source was engaged in commercial or residential work and by their individual experience and preferences. As noted, since HVAC systems are so diverse, its almost like asking an Architect to provide a list of the most common types of Architecture. It’s impossible to list all types so, for the benefit of this course audience, below is a list of the most commonly listed types of HVAC systems:

[43] En.wikipedia.org/Air conditioning
[44] ibid

COMMERCIAL[45]

Single-Split System

Single-split systems are a common choice for commercial buildings, particularly for small offices or retail spaces. This type of system consists of an outdoor unit containing the compressor and condenser and an indoor unit with an evaporator and fan. Refrigerant lines connect the two units, enabling heat transfer and air conditioning.

Advantages and Disadvantages

One of the main advantages of single-split systems is their affordability and relatively simple installation. Additionally, they allow for independent temperature control in each room, so you can tailor the comfort levels to suit each space. However, a significant downside is that single-split systems require an outdoor unit for each indoor unit, which can take up valuable outdoor space and be aesthetically unappealing.

Ideal Applications

Single-split systems are an excellent option for small commercial spaces like offices, retail shops or restaurants, where individual temperature control is necessary and space to accommodate multiple outdoor units is available.

Multi-Split System

A multi-split system consists of several indoor units connected to a single outdoor unit. It uses advanced inverter technology to provide more efficient and precise temperature control. The indoor units can be either wall-mounted, floor-standing or concealed within the ceiling for a more discreet appearance.

Advantages and Disadvantages

The main advantage of a multi-split system is the ability to connect multiple indoor units to a single outdoor unit, saving outdoor space and potentially providing a more aesthetically pleasing solution. Additionally, it offers greater design flexibility as the indoor units can be customized to suit the specific requirements of each room. However, multi-split systems can be more complex and expensive to install and may require more sophisticated controls and maintenance.

Ideal Applications

Multi-split systems are best suited for larger commercial spaces, such as office buildings, hotels or retail complexes, where multiple rooms or zones

[45] https://www.airproductsinc.com/blog/2023/04/a-guide-to-the-different-types-of-commercial-hvac-systems; April 28, 2023

require individual temperature control and a single outdoor unit is preferable.

VRF/VRV System

Variable refrigerant flow (VRF) or variable refrigerant volume (VRV) systems are advanced HVAC solutions designed to provide efficient and precise temperature control for large commercial or multi-story buildings. These systems consist of an outdoor unit, which can be connected to multiple indoor units. They also use sophisticated controls to modulate the flow of refrigerant based on the cooling or heating requirements of each zone in the building.

Advantages and Disadvantages

VRF/VRV systems are highly energy-efficient and capable of providing simultaneous heating and cooling. Furthermore, they offer exceptional flexibility in terms of design and installation. They also require less space for outdoor units as one unit can serve multiple indoor units. However, these systems can be quite complex and costly to install and maintain and may not be suitable for small or simple commercial spaces.

Ideal Applications

VRF/VRV systems are best suited for large or complex commercial buildings, such as hotels, office complexes or multi-story residential buildings, where sophisticated temperature control and energy efficiency are essential.

Heat Pump System

A heat pump system uses the principle of heat transfer to provide both heating and cooling for a commercial space. It consists of an outdoor unit, which houses the compressor and condenser, and an indoor unit with an evaporator and fan. During the winter months, the system extracts heat from the outdoor air and transfers it to the indoor unit, providing warmth. In the summer months, the process is reversed, and heat is extracted from the indoor air and transferred outdoors.

Advantages and Disadvantages

Heat pump systems are known for their high energy efficiency and low operating costs, as well as their ability to provide both heating and cooling without the need for separate systems. However, heat pumps are generally less effective in extreme temperature conditions and may require supplemental heating or cooling in some climates.

Ideal Applications

Heat pumps are suitable for commercial buildings in mild to moderate climates, where heating and cooling requirements are relatively balanced throughout the year. Examples include office buildings, retail spaces or schools.

Geothermal System

Geothermal HVAC systems use the stable temperatures of the earth to provide heating and cooling for commercial buildings. They consist of an outdoor loop of buried pipes, which circulate a heat transfer fluid, and an indoor unit with a heat exchanger and fan system. Depending on the season, the system either extracts heat from the earth or releases excess heat underground.

Advantages and Disadvantages

Geothermal systems are incredibly energy-efficient and environmentally friendly, with low operating costs and minimal greenhouse gas emissions. However, the installation process is complex and costly as it requires underground excavation and specialized equipment.

Ideal Applications

Geothermal HVAC systems are ideal for commercial buildings in locations where land is available for the installation of underground loops. Their long-term benefits of energy efficiency and environmental sustainability outweigh the initial installation costs.

RESIDENTIAL

The table below published in Today's Homeowner blog is a good summary for reference[46]:

Type of HVAC	Heating or Cooling	Advantages	Drawbacks
Central Air Conditioner	Cooling	Affordable and long-lasting	Requires a separate heating system
Furnaces	Heating	Very efficient	Needs a lot of maintenance
Ductless Mini-Splits	Heating and Cooling	More affordable than a heat pump and can both heat and cool your home	You need one for each room

[46] https://todayshomeowner.com/hvac/guides/types-of-hvac-systems; December 31, 2023

Type of HVAC	Heating or Cooling	Advantages	Drawbacks
Heat Pump	Heating and Cooling	Keeps your home comfortable year-round	Higher upfront cost
Packaged Terminal AC Systems	Heating and Cooling	Easy to maintain all-in-one unit	Heating capacity isn't enough for colder climates
Window and Wall-Mounted ACs	Cooling	Very affordable and easy to install	Not as efficient as other options and doesn't provide heat

Two other systems that architects should be aware of are Boilers and Chillers, especially if the project is large.

> Boilers and chillers tend to work best for industrial or commercial applications. These pieces of equipment are heavy-duty enough for heating large industrial facilities comfortably and for keeping equipment cooled down. A chiller removes heat from liquid through either vapor compression or an absorption refrigeration cycle and sends the cooled liquid through a system of pipes and coils in air handlers or fan-coil units. There are many different types of chillers to choose from, depending on your needs. A boiler heats fluid until it becomes hot or even until it vaporizes. The system produces radiant heating that gets distributed through baseboard radiators, radiant floor systems or a coil in the case of hot fluid and through radiators in the case of steam. Chillers and boilers are an option for residential applications, but their most valuable application tends to be industrial facilities.[47]

Some further terms to be aware of the main components of any HVAC system.

COMPONENTS of an HVAC SYSTEM:

Ducts

Ducts are conduits or passages used in heating, ventilation, and air conditioning to deliver and remove air. The needed airflows include, for example, supply air, return

[47] Rea Christian, iwae.com/resources

air, and exhaust air. Ducts commonly also deliver ventilation air as part of the supply air[48].

Compressor

A compressor is a mechanical device that increases the pressure of a gas by reducing its volume. An air compressor is a specific type of gas compressor. Compressors are similar to pumps: both increase the pressure on a fluid and both can transport the fluid through a pipe.[49]

Blower Motor

An HVAC blower motor is the component that turns on the system's fan that pushes the hot or cold air out of the unit and into the space. Air heating systems such as electric and gas furnaces, air conditioners, heat pumps, and mini splits all utilize a blower motor to transfer this air.[50]

Condenser

In systems involving heat transfer, a condenser is a heat exchanger used to condense a gaseous substance into a liquid state through cooling. In so doing, the latent heat is released by the substance and transferred to the surrounding environment. Condensers are used for efficient heat rejection in many industrial systems. Condensers can be made according to numerous designs and come in many sizes ranging from rather small (hand-held) to very large (industrial-scale units used in plant processes). For example, a refrigerator uses a condenser to get rid of heat extracted from the interior of the unit to the outside air.[51]

Condenser Coil

Condenser coils are used to reject heat from an air-conditioning or refrigeration system. Sometimes they are used with the intention to heat air streams. They are one of the four main components in the refrigeration or air-conditioning cycle. Refrigerant enters as a superheated gas and condenses in the coil tubes as the air is heated. The refrigerant leaves the coil as a liquid.[52]

Evaporator Coil

An evaporator coil is the opposite of the condenser coil, most often located on the top of the indoor unit box. The coils work by absorbing heat from the indoor air, as the furnace blower blows warm air over them. The heat present in the indoor air is

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[48] wikipedia
[49] ibid
[50] Aireserv.com
[51] https://en.wikipedia.org/wiki/Condenser_(heat_transfer)
[52] Emergrntcoils.com

transported to your system's condenser coil through the gaseous refrigerant, where it is released to the exterior.[53]

Refrigerant Lines

A Refrigerant Line is a copper line that connects the outdoor air conditioner or heat pump to the indoor evaporator coil.[54]

Combustion Chamber

Often called a burner, the combustion chamber is the component of the HVAC system that allows the air to be heated up. This is where air is added by the furnace and a combustible material combine with a source of ignition to heat up. In more modern HVAC systems, this is done using a glow stick, which lights automatically. Older systems use a pilot light, which can often go out and needs to be relit. They also can cause emission of carbon monoxide and are thus not the most efficient or convenient method.[55]

Air Handler

An air handler, or air handling unit (often abbreviated to AHU), is a device used to regulate and circulate air as part of a heating, ventilating, and air-conditioning (HVAC) system.[1] An air handler is usually a large metal box containing a blower, furnace or A/C elements, filter racks or chambers, sound attenuators, and dampers. Air handlers usually connect to a ductwork ventilation system that distributes the conditioned air through the building and returns it to the AHU, sometimes exhausting air to the atmosphere and bringing in fresh air. Sometimes AHUs discharge (supply) and admit (return) air directly to and from the space served without ductwork.

Small air handlers, for local use, are called terminal units, and may only include an air filter, coil, and blower; these simple terminal units are called blower coils or fan coil units. A larger air handler that conditions 100% outside air, and no recirculated air, is known as a makeup air unit (MAU) or fresh air handling unit (FAHU). An air handler designed for outdoor use, typically on roofs, is known as a packaged unit (PU), heating and air conditioning unit (HCU), or rooftop unit (RTU).[56]

Chiller

A chiller is a machine that removes heat from a liquid coolant via a vapor-compression, adsorption refrigeration, or absorption refrigeration cycles. This liquid can then be circulated through a heat exchanger to cool equipment, or another

[53] Cloverco.com
[54] https://www.lennox.com › guide-to-hvac › glossary
[55] https://www.fagoneplumbing.com/blog-1/2020/2/27
[56] https://en.wikipedia.org/wiki/Air_handler

process stream (such as air or process water). As a necessary by-product, refrigeration creates waste heat that must be exhausted to ambience.

In air conditioning systems, chilled coolant, usually chilled water mixed with ethylene glycol, from a chiller in an air conditioning or cooling plant is typically distributed to heat exchangers, or coils, in air handlers or other types of terminal devices which cool the air in their respective space(s). The water is then recirculated to the chiller to be re-cooled. These cooling coils transfer sensible heat and latent heat from the air to the chilled water, thus cooling and usually dehumidifying the air stream.[57]

Evaporator Coil

An evaporator coil is the opposite of the condenser coil, most often located on the top of the indoor unit box. The coils work by absorbing heat from the indoor air, as the furnace blower blows warm air over them. The heat present in the indoor air is transported to your system's condenser coil through the gaseous refrigerant, where it is released to the exterior.[58]

Filter

A filter is the porous component of the HVAC system that helps to trap dust particles, allergens, and other impurities present in the air that gets into your house. It purifies the air, making it safe to breathe. This way, the outdoor air sucked into the interior space by the AC fan doesn't bring in impurities or pollutants.[59]

Dampers

A damper is also a crucial part of your HVAC components diagram. Generally, it is designed to control or regulate airflow within the HVAC system. It may be used to regulate airflow in ducts, VAV boxes, chimneys, or air handlers. It is quite helpful in cutting off airflow to unused rooms.[60]

Vents

Air passes from the duct system into rooms via metal vents. These are made of a material that resists hot and cold temperatures. Located on or close to the ceiling, AC vents usually have movable slats that control airflow and the amount of cooling/heating a room receives.[61]

Humidifier

The humidifier, a vital HVAC component, adds moisture to indoor air using water or steam. This enhances comfort and occupants' health while preventing dryness,

[57] https://en.wikipedia.org/wiki/Chiller
[58] Cloverco.com
[59] ibid
[60] ibid
[61] https://callairstars.com/air-conditioning/what-are-the-main-components-of-an-hvac-system/

static electricity, and damage to woodwork and furniture. Humidifiers can be standalone units or part of the air handler or furnace. These devices are controlled by a humidistat and efficiently measure and regulate indoor humidity levels.[62]

Boiler

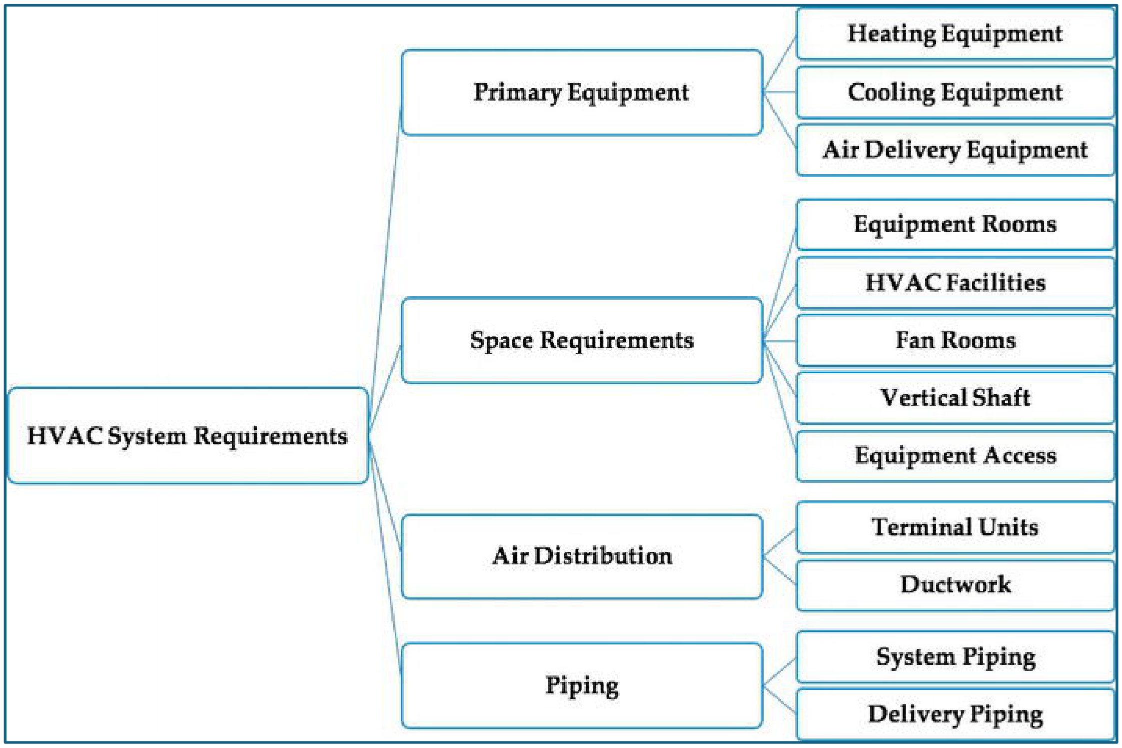
The boiler is a part of the HVAC system responsible for heating the water or the steam. It is a unit that uses a burner, a heat exchanger, a pump, and a flue to heat the water or the steam and raise its temperature and pressure. The boiler can use different fuel types, such as natural gas, propane, oil, or electricity, to create the heat. The boiler can provide hot water or steam to the fan coil units, the air handlers, or the heat pumps, which can heat the air in the indoor space.[63]

Thermostat

The thermostat is the component of the HVAC system the user interacts with the most. It controls the heating and cooling units based on your preferred settings. The thermostat lets you adjust your HVAC system's temperature, fan speed, mode, and schedule. Different types of thermostats, including manual, programmable, and intelligent, offer additional features and benefits.[64]

Knowing the components and types of systems is good information, but it is also important to understand how HVAC system requirements are determined. The flow chart below illustrates the way an HVAC system is broken down:

[62] https://squarehvac.com/parts-of-hvac-system/
[63] ibid
[64] ibid



Source: HVAC System "Types of HVAC Systems" by Shaimaa Seyam[65]

2.3. How an HVAC engineer Evaluates a Building Design

The preceding section was intended to familiarize an architect with the terminology of the HVAC engineer. This understanding is not a basis to make HVAC decisions; it is simply to enable an informed conversation and decision-making dialog to proceed between the architect and HVAC engineer. The other key factors to understand are how an HVAC engineer approaches and evaluates an architect's building design. Ultimately, these are the factors that the architect can influence to support "friendlier" outcomes from the HVAC system. It is not the architect's domain, nor qualifications to actually design and /or fine tune the mechanical and controls designs of the HVAC system.

So, what does an HVAC engineer expect when dealing with an Architect?

Broadly there are five stages of interaction and information that the HVAC engineer solicits from the architect:

1. **Basic Project Design Data**. This is the general site and building design data that helps an HVAC engineer assess the building needs in terms of the environment where the building is situated and what limitations of space and building design concept will have to be overcome. This information includes:
    - Project location.

[65] Seyam S (2018) Types of HVAC Systems. HVAC System. InTech. Available at: http://dx.doi.org/10.5772/intechopen.78942.

- Ambient climatic conditions at the location.
- Project performance requirements – what are the expected interior comfort parameters for the occupants.
- Any special equipment or functional requirements for HVAC – such as special cooling for computer rooms; once through air flow for laboratories; special filtration for clean rooms or medical facilities.
- Building perimeter size, number of stories and interior volumes.
- Building orientation – in terms of how windows and other openings are oriented relative to wind directions, sun angles and physical characteristics of the surrounding area – to establish shading effects of surrounding trees, geographic features and physical structures.
- Information on any atmospheric concerns like nearby industrial pollutants or hazardous classifications.
- Information related to any blast resistance requirements on the redundancy of equipment.
- Shelter in place requirements, if any, for buildings in areas prone to natural disasters or near high-risk industrial facilities.
- Available area for HVAC equipment – inside, outside and on rooftops.
- Initial design concept for the building relative to wall and ceiling configurations, insulation considerations, exterior envelope materials and construction philosophy.

Based on the above information, the HVAC engineer will develop a concept that seems best suited technically for the site and functional requirements. An initial recommendation on the type of system to be used and potential physical placement of the components will be determined.

2. **Options Evaluation and Stylistic Considerations**. Once the recommendation is made to the architect, discussions will be held to decide on see how the proposed system will work with the building layout, site implications for exterior equipment and access and maintenance facilitation of roof and ceiling mounted equipment. Discussions between architect and HVAC engineer at this stage include the following types of issues:
    - System design – type, size, configuration, and cost.
    - Interior space needs – Mechanical room(s), ceiling plenum space, overhead or underfloor duct systems
    - Exterior equipment placement – impact on views, pedestrian and vehicular circulation, and maintenance access and servicing.

- Zoning of air flow and temperatures – by this time the architectural design should be developed to a point where the architect can express the desired zoning of thermostats to control temperature and air flow in selected zones. Depending on the proposed system, the HVAC engineer can advise on the most practical and feasible options. Sometime the evolving specifics of the project need can require a reexamination of the initial proposed system.
- Architectural style and HVAC integration. This is also the stage where the building design style is generally set and the architect can advise the HVAC engineer about any stylistic considerations or concealment – for example whether to expose and highlight the HVAC system as an expression of design such as the Center Pompidou mentioned previously (albeit this is an extreme example but milder expressions are not that rare). Another option may be to expose but "ghost" the HVAC system – a common technique in restaurants and clubs where the ceiling and all HVAS ducts and registers are painted monotone, thus making them fade from visual attention. Or the building may be a conventional type of commercial space where "standard" HVAC systems are adequate.
- In special design projects where design and expression of that design is integral to all features, the architect will get involved with the HVAC designer to seek solutions that match the design. This can involve custom grilles, special control systems, sound control, careful duct placement – whether exposed or concealed, and sometime innovative solutions. These types of projects can be commercial or residential but are generally unique and with substantial budgets.

At this point the HVAC engineer usually has sufficient understanding of the project to start doing a design of the technical requirements for the system so the proper equipment and components can be sized, availability checked, and budgets validated.

3. **The Load calculation**. Based on the above, the HVAC engineer conducts what is called a Load Calculation. The goal of an HVAC load calculation is to determine the right size of equipment needed to keep the interior temperature comfortable while using as little energy as possible. This type of calculation takes into account factors such as insulation, window areas, and the number of occupants in each room. It also considers regional climate conditions like temperatures, humidity levels, and wind speeds. The results from this calculation are used to select appropriate air conditioning units and furnaces

that will provide adequate cooling and heating throughout the year with minimal energy usage.[66] The figure below illustrates a Load Calculation table:

[66] Buildops.com: "How to do a Load Calculation HVAC", February 13, 2023

HVAC QUICK LOAD PROGRAM

COMPANY:		DATE:	Oct 28, 2016
PROJECT:		PROJ. NO.:	

AHU #	MONTH (1-12)	TIME (7am-6pm)	OUTDOOR AIR TEMPERATURES SUMMER		WINTER	INDOOR AIR TEMP	RH = 50.0% RH
AHU-1	8	5	94.0°F db	74.0°F wb	12.0°F	72.0°F db	60.1°F wb

AHU TYPE BLOWTHRU = BT DRAWTHRU = DT	HOURS OF OPERATION (12, 16, 24)	"U" VALUES WALL	ROOF	GLASS	GLASS SAFETY FACTORS BARE	SHADED
DT	24	0.10	0.08	1.13	0.80	0.65

GLASS SOLAR HEAT GAIN

INT SHADE ? (Y/N)	EXPOSURE	AREA (SQ.FT.)	PEAK SOLAR HEAT GAIN	24 HR STORAGE	SHADE FACTOR	SAFETY FACTOR	BTU/HR
N	N	100	37	0.80	0.80	1.10	2,605
N	S	100	111	0.45	0.80	1.10	4,396
N	E	100	219	0.20	0.80	1.10	3,854
N	W	100	219	0.48	0.80	1.10	9,251
N	NE	100	141	0.17	0.80	1.10	2,109
N	NW	100	141	0.40	0.80	1.10	4,963
SKYLIGHT	HORIZ.	100	225	1.00	1.00	1.10	24,750
						SUB-TOTAL =	51,928

TRANSMISSION HEAT GAIN

	EXPOSURE	AREA (SQ.FT.)	EQUIVALENT TEMP. DIFF.	TEMP. CORRECTION	"U" VALUE	SAFETY FACTOR	BTU/HR
WALL:	N	100	11	10	0.10	1.10	231
WALL:	S	100	23	10	0.10	1.10	363
WALL:	E	100	13	10	0.10	1.10	253
WALL:	W	100	34	10	0.10	1.10	484
ROOF:	HORIZ.	100	43	10	0.04	1.10	233
GLASS:		700	22		1.13	1.10	19,142
PARTITION:		100	10		0.20	1.10	220
						SUB-TOTAL =	20,926

INTERNAL HEAT GAIN

	QUANTITY OR SQ.FT.	WATTS PER SQ.FT.	CONVERT FACTOR	MULTIPLIER FACTOR	SAFETY FACTOR	BTU/HR
FLUOR. LIGHTS (SF):	1000 SF	2.00	3.413	80%	1.10	6,007
INCAN. LIGHTS (SF):	1000 SF	0.25	3.413	100%	1.10	939
POWER (SF):	1000 SF	2.00	3.413	100%	1.10	7,509
EQUIPMENT (SF):	1000 SF	2.00	3.413	100%	1.10	7,509
INFILTRATION SENSIBLE:	100 CFM	22.0°F		1.08	1.10	2,624
					SUB-TOTAL =	27,337

ROOM SENSIBLE HEAT GAIN

TOTAL STATIC = 2.00 in. wg		ROOM SENSIBLE HEAT (BTU/HR)=	100,191
AIRFLOW @ 20.0°F TEMP. DIFF. =	4619 CFM		
MOTOR SIZE = 2.4 BRAKE HORSEPOWER			
MOTOR HEAT RISE = 1.2°F		HEAT GAIN FROM MOTOR (BTH/HR) =	6,165
		SUB-TOTAL =	106,357

RETURN AIR HEAT GAIN

	EXPOSURE	AREA (SQ.FT.)	EQUIVALENT TEMP. DIFF.	TEMP. CORRECTION	"U" VALUE	SAFETY FACTOR	BTU/HR
WALL:	N	10 SF	11	10	0.10	1.10	23
WALL:	S	10 SF	23	10	0.10	1.10	36
WALL:	E	10 SF	13	10	0.10	1.10	25
WALL:	W	10 SF	34	10	0.10	1.10	48
ROOF:	HORIZ.	100 SF	43	10	0.04	1.10	233
LIGHTS:	(FLUOR.)	1000 SF	2.0 W/SF	3.413	20%	1.10	1,502
MOTOR BHP:		2.4 BHP			HEAT GAIN FROM MOTOR =		
						SUB-TOTAL =	1,868

OUTSIDE AIR HEAT GAIN

	CFM PER PERSON	CFM	TEMP. DIFFERENCE	MULTIPLIER FACTOR	SAFETY FACTOR	BTU/HR
O/A SENSIBLE:	375	3750	22.0°F	1.08	1.10	98,418
					GRAND TOTAL SENSIBLE HEAT (BTU/HR) =	206,643

LATENT HEAT GAIN

	CFM OUTSIDE AIR	DELTA GRAINS	MULTIPLIER FACTOR	SAFETY FACTOR	BTU/HR
INFILTRATION LATENT:	100	36	0.68	1.10	2,676
PEOPLE LATENT:	10 PEOPLE @ 200 BTH PER PERSON			1.10	2,200
				SUB-TOTAL =	105,213
				GRAND TOTAL LATENT HEAT (BTH/HR) =	105,213

ROOM SENSIBLE HEAT RATIO =	0.98	GRAND TOTAL HEAT (BTU/HR) =	311,856
TOTAL SENSIBLE HEAT RATIO =	0.66	TONNAGE =	26.0
ENTERING ENTHALPY =	35.4 BTU/LB	ENTERING AIR TEMPERATURE =	89.9°F
LEAVING ENTHALPY =	20.4 BTU/LB	LEAVING AIR TEMPERATURE =	50.8°F

HVAC Load Calculation Sheet*; Source: Engineering Design Resources* [67]

4. **RCP and Fixture Selection**. Once the HVAC engineer has determined their design solution and identified duct sizes, supply and return air zones, thermostat placements and other features of the HVAC design, all of these decisions are generally documented on the RCP (Reflected Ceiling Plan), architectural drawing that forms the basis for coordinating physical locations of HVAC supply and return air registers, vents, lighting and the general ceiling configuration. The reason why this is the document of choice is that the vast majority of lighting and HVAC fixtures are ceiling mounted and that makes this the ideal place to also show related wall mounted elements like thermostats and above ceiling elements like ducts and air control boxes. Typically, the architect generates the desired ceiling configuration and provides a "background" RCP to the HVAC engineer and lighting engineer who add their components. This serves two purposes: Avoids clashes and allows for the aesthetic adjustments that the architect may want.

   During this phase, the architect also reviews the data sheets for HVAC fixtures and any component that is exposed and visible to the building occupants. Primarily this is for the architect to ensure that the placements and design selected by the HVAC engineer conform to the overall design intent of the building and its interior scheme.

5. Building Construction and Occupancy. The interaction between the architect and HVAC consultant tends to be very limited during this phase, usually each keeps to reviewing and resolving their own technical issues. When an issue arises that impacts the aesthetics of the space due to a field conflict, the architect and HVAC consultant may huddle to find a common resolution. At the point of occupancy by the owner the HVAC system is tested and balanced to ensure the design performance criteria are met. Any deficiencies usually involve the architect since most HVAC engineers work through the architect as consultants to the architect.

The above discussion illustrates how the relationship between architects and their HVAC consultants has evolved into a generally one-way transactional one. Architects provide their requirements and HVAC engineers offer solutions. Architects review, select the superfluous elements and move on. In the pre-HVAC era, architects had to engage actively in the design of comfort for the buildings occupants as we have discussed in Part 1 of this course. HVAC, particularly the AC part, created the ability to climate control any space anywhere. Architects quickly disengaged from addressing how the design decisions they make can have huge impacts on the efficiency and environmental impact of the HVAC

[67] https://engineeringdesignresources.com/hvac-design/

systems. In Part 3 of the course we will discuss why and how architects need to re-engage and become integral partners with HVAC engineers to address the increasingly alarming concerns over climate change and the mandates like NetZero that are emerging from this "crisis". Regardless of the climate change or Global warming debate, the aims of NetZero are pushing design towards a better, humane and sustainable direction that can only improve the built environment after decades of mechanized, enclosed indifference.

2.4. Impact of HVAC on Climate Change

An article by Sherri Hartsell titled "Air Conditioning and Urban Growth" published on medium.com on September 17, 2021 had a very telling sub heading: "How cooling our homes is warming our cities". Very catchy but also a statement of some truth. Ms. Hartsell argued that "Thanks to the invention of the air conditioning (AC) system, those with the luxury of living and working in temperature regulated environments are able to seek refuge from rising temperatures. AC cooling systems have made our cities and built environments more hospitable in otherwise hot and humid climates. This has stimulated urban and economic growth worldwide and pulled some nations out of poverty. As urban populations continue to grow, the increased demand of ACs have put a strain on global energy systems. Since most energy systems rely on non-renewables as a primary source for production, the use of AC cooling systems are inadvertently contributing to global warming effects and climate change impacts."[68]

While it may seem convenient, even popular, to blame AC systems for climate change, the underlying question is not whether AC is causing the problem or whether it is the reckless and frenzied adoption of then technology that must share some responsibility. As noted in the previous section, architects effectively took themselves out of the equation and so did city planners in ignoring nature friendly design options when developing communities and buildings that no longer cared about respect for natural air flows and light. As buildings got taller, communities got more densely congested and air more stifling and stagnant, HVAC systems have become a solution to human survival, almost a necessity in some areas.

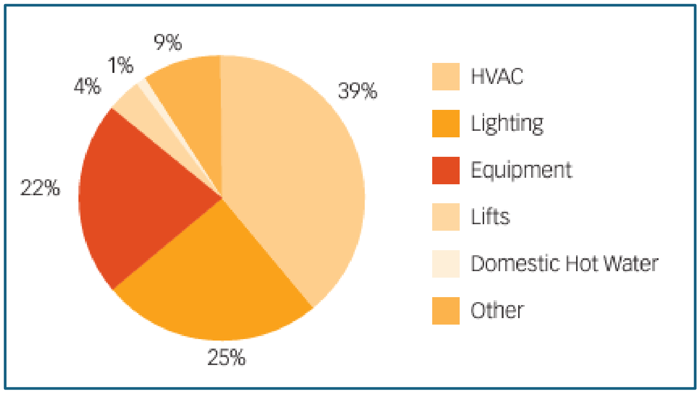
So, what are the ways in which HVAC systems impact the environment:

1. **Electricity consumption**: HVAC, particularly the AC systems are energy hogs. To put that into perspective, a study from Australia by energy.gov.au found the following results:

   > "Heating Ventilation and Air Conditioning (HVAC) is generally responsible for a significant proportion of total building energy consumption. A typical system accounts for approximately 40% of total building consumption and 70% of base building (i.e. landlord) consumption. The pie graph below

[68] https://medium.com/@SherriHartsell/air-conditioning-and-urban-growth Sep 17 2021

shows the typical energy consumption breakdown of an office building, being 39% HVAC, 25% lighting, 22% equipment, 4% lifts, 1% domestic hot water and 9% other."[69]



While this study reflects consumption in an office building, the results are applicable to most commercial building types using central AC, including residential. In the US, the largest electricity consumer in the average household is the heating and cooling system. Responsible for 45-50% of total electricity usage. [70]

As AC demand skyrockets worldwide, the power needed to run these systems requires more electricity generation. That has its obvious impacts on CO_2 emissions since most power plants are still coal or hydrocarbon based.

AC units overtake the building facade

2. **AC systems use refrigerant to cool.** Almost all AC systems use some form of refrigerant for cooling. Hydrocarbon refrigerants are synthetic compounds that contain no chlorine or bromine atoms. These refrigerants, also called HFCs,

[69] Energy.gov.au/HVAC factsheet; September 2013
[70] Perchenergy.com; Dec 20,2022

have been developed to replace ozone-depleting chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs).[71] The refrigerant starts as a liquid and expands into a gas, which forces it to cool down. This chilled gas circulates through the fridge, absorbing heat. The refrigerant flows through condenser coils where it releases its heat out and cools back into a liquid. Air conditioners release their heat to the outdoors. (This is the global warning part). Refrigerants have been the major source of environmental concern.[72]

Some of the earlier refrigerant chemicals that allowed hot places like Phoenix, Arizona and Dubai to grow into population centers, were a family known as chlorofluorocarbons (CFCs), but scientists discovered that these were causing widespread damage to the ozone layer in the mid to late 1900s.[73]

In response, countries came together and ratified the Montreal Protocol which went into effect in 1987 and banned CFCs. This is cited as one of the most successful international environmental laws ever. The family of chemicals that replaced those CFCs was hydrofluorocarbons or HFCs. They were first commercialized in the 1990s. But these were found to be dangerous for the climate and were rapidly building up in the atmosphere as air conditioning spread across the world.[74]

The way to compare damaging gases is “global warming potential” or GWP, which the Environmental Protection Agency defines as how much energy one ton of a gas can absorb over a certain period of time, compared to one ton of carbon dioxide. Over one century, the GWP of carbon dioxide is one, therefore. Methane, the second most important greenhouse gas after carbon dioxide is 28, or 28 times worse. The common refrigerant known as R-410A, has a global warming potential of 2,088.[75]

3. **Materials**. HVAC systems utilize a lot of metals in their fabrication and with the proliferation of the AC systems, especially to lower cost ones, the lifecycles of these units can be relatively short. This necessitates replacement or overhauls. The disposal of waste materials is not well regulated and generally done without much thought to recycling. The refrigerant in discarded systems is supposed to be captured for reuse or proper disposal but in many parts of the world, the cost is not worth the effort, and it is simply leaked to the atmosphere. This

[71] https://advanced-commercial.com/refrigerant
[72] Seattle Times, “When it comes to heating the planet, the fluid in your AC is thousands of times worse than CO2” by Isabella O’Malley; AP, Oct 13, 2023
[73] ibid
[74] ibid
[75] ibid

> widespread apathy towards material disposal is a significant contributor to HVAC's negative environmental footprint. In recent years, with increased global awareness and, at least tacit, political backing of NetZero targets, more countries are imposing regulatory controls on refrigerant leakage, with hefty fines for violations and even criminal prosecution. In the United States, the Environmental Protection Agency (EPA) regulations under Title VI of the Clean Air Act (CAA) are designed to protect the ozone layer and to provide for a smooth transition away from ozone-depleting substances (ODS). The EPA is also charged with enforcing these regulations. Enforcement actions range from civil fines to criminal prosecutions. Enforcement is performed within EPA by the Office of Enforcement and Compliance Assurance.[76] One mechanism to support enforcement is by encouraging members of the public to report violations with potential promises of monetary rewards upon convictions of violators. In practice, these are seldom paid. On the other side there are precedents for criminal prosecution. In 2014, an Ohio man was sentenced to 31 months in jail for releasing HCFC-22 (R-22) into the atmosphere when he attempted to sell the copper piping from 49 stolen AC units.[77]

As noted above, the environmental harm from HVAC systems is not so much due to inherent harmful design but due to the proliferation of systems without proper planning of the consequences and then sloppy management of disposal. These circumstances still do not excuse the fact that there is impact on the environment from HVAC usage and that ties in to the complex set of factors that are cumulatively contributing to climate change and the phenomenon popularly dubbed "Global Warming". According to The National Renewable Energy Laboratory (NREL), "The researchers calculated air conditioning is responsible for the equivalent of 1,950 million tons of carbon dioxide released annually, or 3.94% of global greenhouse gas emissions. Of that figure, 531 million tons comes from energy expended to control the temperature and 599 million tons from removing humidity. The balance of the 1,950 million tons of the carbon dioxide come from leakage of global-warming-causing refrigerants and from emissions during the manufacturing and transport of the air conditioning equipment. Managing humidity with air conditioners contributes more to climate change than controlling temperature does. The problem is expected to worsen as consumers in more countries—particularly in India, China, and Indonesia—rapidly install many more air conditioners."[78]

Despite all the preceding criticism, it should be understood that HVAC systems have made tremendous progress over the past several years and even more dramatically since the

[76] EPA.gov: "Enforcement Actions under Title VI of the Clean Air Act"
[77] https://www.justice.gov/usao-sdoh/pr/air-conditioner-thief-pleads-guilty-violating-clean-air-act
[78] NREL.gov: "Scientists Show Large Impact of Controlling Humidity on Greenhouse Gas Emissions"; March 14, 2022.

NetZero targets were ratified in 2015 at the Paris Agreement (COP21). These will be discussed more fully in Part 3 of this course.

This concludes Part 2 of the course.

Part 2 Review Questions

11. Ventilation is the management of air flow through an interior space. Ventilation can be achieved in a building by ________ methods.

a. 2
b. 3
c. 4
d. 5

12. _____________ are conduits or passages used in heating, ventilation, and air conditioning to deliver and remove air.

a. Ducts
b. Condenser
c. Evaporator Coil
d. Filter

13. What applications is a Multi-Split system ideally suited for?

a. Small commercial spaces like retail shops.
b. Retrofit of old historic buildings.
c. Large or complex commercial buildings like hotels or office complexes.
d. Single family suburban homes

14. Geothermal systems are incredibly ______________ and environmentally __________, with _____ costs...

a. Expensive, harmful, high
b. Powerful, friendly, moderate
c. Energy-efficient, friendly, low
d. Safe, sustainable, low

15. The _____________ is a crucial part of an HVAC components diagram and is designed to control or regulate airflow within the HVAC System.

a. Chiller
b. Combustion Chamber
c. Damper
d. Vent

16. The ____________________ is the component of the HVAC the user interact with the most and controls the heating and cooling units based on preferred settings.

a. Humidifier
b. Boiler;
c. Filter
d. Thermostat

17. What is the difference between an Air Handler and a Chiller?

a. An Air Handler absorbing heat from the indoor air, as the furnace blower blows warm air over them while a Chiller adds moisture to indoor air using water or steam
b. An air handler, or air handling unit (often abbreviated to AHU), is a device used to regulate and circulate air as part of a heating, ventilating, and air-conditioning (HVAC) system while a Chiller is a machine that removes heat from a liquid coolant via a vapor-compression, adsorption refrigeration, or absorption refrigeration cycles.
c. An Air Handler regulates the temperature at which air is blown into a space while a Chiller regulates water flow into the Air handler.
d. They are synonymous terms.

18. For basic project design data, which of the following is considered information that an HVAC engineer would obtain from an architect?

a. Project location
b. Building perimeter size, number of stories and interior volumes
c. None of the above
d. Both a & B

19. What determines the right size of equipment needed to keep the interior temperature comfortable while using as little energy as possible?

a. Options evaluation and Stylistic Considerations
b. The Load Calculation
c. RCP and Fixture Selection
d. Basic Project Design Data

20. What was banned as a result of the Montreal protocol?

a. Carbon Dioxide
b. Ozone
c. Chlorofluorocarbons (CFCs)
d. All of the above

In this Part 3 of the course, the following topics will address how newer systems and better design considerations can lead to an optimized approach to HVAC design where both the architect and HVAC engineer become more integrated:

- Recent advances in HVAC designs in response to Climate Change and NetZero challenges
- An examination of architectural design elements and functions that influence HVAC systems.
- How architectural design considerations (passive and active) can help simplify and reduce loads on an HVAC system.
- The importance of collaboration between HVAC consultant and architect in developing joint design strategies.
- The link between optimizing HVAC design and attainment of sustainability and NetZero targets.
- The integral nature of optimization of HVAC system and its direct link to the optimization of architectural design.

PART 3 – Architectural Design Influence to Optimize HVAC

3.1. Recent advances in HVAC designs?

As has been noted previously, AC proliferation began in the 1960s and started reaching global adoption in the 1970s. Not soon afterwards, it was noted by scientists that a group of chemicals called chlorofluorocarbons (CFCs) was causing serious damage to the ozone layer of the earth's atmosphere, resulting in measurable depletion to the point that an ozone hole in the layer was detected above the Antarctic. The seriousness of this issue and the direct link to the CFCs led to the adoption of what became known as The Montreal Protocol. Finalized in 1987, it is a global agreement to protect the stratospheric ozone layer by phasing out the production and consumption of ozone-depleting substances (ODS).[79] While CFCs were most commonly used in hygiene products and aerosols, they were also widely used in refrigeration, including air conditioning systems. With the agreement to ban

[79] https://www.state.gov/key-topics-office-of-environmental-quality-and-transboundary-issues

all CFCs by 2010, this was an environmental wake up call for the refrigerant industry to become more aware of the potentially negative impacts of their products on the atmosphere.

In parallel, there was also growing public awareness about the steady rise in power consumption worldwide due to the revolution in consumer appliances ranging from refrigerators to stoves, washing machines, air conditioning and a rapidly snowballing plethora of other convenience devices. To help incentivize manufacturers to make these products as energy efficient as possible, in 1992, the US Environmental Protection Agency (EPA) introduced ENERGY STAR as a voluntary labeling program designed to identify and promote energy-efficient products to reduce greenhouse gas emissions. Computers and monitors were the first labeled products.[80] The program has expanded significantly since then. The Energy Star label is found on more than 75 different certified product categories, homes, commercial buildings, and industrial plants. In the United States, the Energy Star label is also shown on the Energy Guide appliance label of qualifying products. Elements of the Energy Star Program are being implemented in Japan, Taiwan, and Switzerland, as well as by Energy Star Canada. In 2018, a 15-year long agreement with the European Union expired.[81] Among the categories of products participating in the program are most of the major HVAC manufacturers. ENERGY STAR certified central air conditioners have higher seasonal energy efficiency ratio (SEER) and energy efficiency ratio (EER) ratings and use 8 percent less energy than conventional new models.[82]

While refrigerant reformulations and energy efficiency drove much innovation, it was not until the 2010s that serious rethinking started about not just simply making air conditioners more efficient but also finding ways to use less of them and, where they are used, use them less frequently. Added to this, the trend towards ecological awareness in products, advances in automation technology and emergence of Artificial Intelligence are having a revolutionary impact on HVAC systems. Some of the notable trends in the HVAC industry that are aimed at optimizing the systems are listed below:

Connectivity and Data to Improve Control[83]

The way buildings are constructed today is a bit different. Many contractors and architects are designing with "green" thinking in mind, which has led to an influx in the installation of smart meters, thermostats, and sensors to help ease power costs. Not only are building owners able to control temperatures, but they're able to control the humidity levels and airflow as well.

They're doing this all from their desktop, tablet, or smartphone. How is this possible? Through robust Wi-Fi-connected software. Now landlords, owners,

[80] https://www.energystar.gov/about/history

[81] Wikipedia: Energy Star

[82] https://www.energystar.gov/products/central_air_conditioners

[83] https://www.mpofcinci.com/blog/emerging-trends-that-are-reshaping-the-commercial-hvac-industry; by Chris Carter, September 7, 2023.

property managers, and maintenance techs can easily monitor and control the atmosphere of a building.

To take things even further, the software-enabled HVAC systems are collecting data and compiling it into reports to identify usage trends, system status, and past performance, which can be used to inform preventive maintenance and identify the source when something malfunctions for faster repairs. Durable nameplates allow technicians to quickly identify components, specifications, source parts for repairs and scan a barcode to document maintenance and repair activities. Some modern software-enabled HVAC systems can self-diagnose, allowing HVAC techs to quickly repair issues to minimize downtime.

Eco-Friendly HVAC Systems Are in Demand[84]

Green initiatives are big business today. Everyone's looking to save money (and the world). So, there's an uptick in the trend for environmentally friendly HVAC units, which includes the use of solar panels and wind turbines to reduce energy costs.

The use of geothermal heating and cooling methods is also on the rise, which eliminates the need for petroleum-based electricity. Instead, these heat pumps use the ground and water sources, such as ponds, to generate energy to heat and cool buildings. Some buildings incorporate a mix of gas and solar, allowing owners to switch between the two seamlessly to control power costs. There are already thermally driven ACs in development.

"Smart" HVAC Technologies Designed for Automation[85]

Technology is at the forefront of many HVAC trends because it's accessible and a lot smarter. The HVAC designs contractors can implement today come with sensors that "talk" to one another. What this means is that buildings have different systems that communicate. For example, occupancy sensors manage interior temperature and humidity levels, along with the lighting.

These systems can also track the conditions outdoors, such as temperature, humidity, brightness, and position of the sun. For instance, if one part of a building isn't in direct sunlight, then the system will blow less AC during the summer and more heat during the winter months. If there are smart blinds installed, the system can open and close the blinds based on the position of the sun. Building automation systems (BAS) are growing in popularity because of the energy-saving capabilities and convenience.

HVAC Systems Are Going Ductless[86]

[84] ibid
[85] ibid
[86] ibid

Updating older buildings with air conditioning is next to impossible, especially if there's not enough space to install ductwork. For buildings that do have space, the expense of these updates can be a bit high for customers. The workaround on both ends is ductless heating and cooling units.

You can install these compact units virtually anywhere, without the need for duct installations. Ductless HVAC units are also the perfect solution for modern infrastructures dealing with holes and gaps in ductwork that cause air leaks. Rather than paying for pricey replacements, they can opt to go with ductless HVAC systems.

Increased Adoption of Heat Pumps[87]

The HVAC industry is adopting more heat pumps because of their energy efficiency and eco-friendliness. The devices, which transfer heat to warm or cool spaces, are less energy-intensive than traditional systems and offer year-round climate control.

The shift is driven by efforts to cut carbon emissions and increase the use of renewables. Heat pumps are attractive for their potential to lower energy costs and fossil fuel use.

The growing preference for heat pumps is transforming the HVAC sector by fostering sustainable practices and improving energy efficiency.

This is expected to decrease energy consumption and progress toward greener HVAC methods.

Reduced HFC Production[88]

The HVAC industry is preparing for a significant reduction in hydrofluorocarbon (HFC) production, a move mandated by the American Innovation and Manufacturing Act (AIM Act)

The AIM Act directs the U.S. Environmental Protection Agency to phase down the production and consumption of HFCs in the United States by 85% over the next 15 years (from 2023). Reducing HFC production is a critical step towards sustainability since HFCs are commonly used refrigerants with high global warming potential.

By limiting their use, the HVAC industry is expected to pivot towards alternative refrigerants with lower environmental impact.

According to the EPA's report, the phasedown is projected to reduce global warming by up to half of one degree Celsius by 2100, marking a substantial contribution to global climate change efforts. This legislative push will likely

[87] https://www.motili.com/blog/upcoming-hvac-trends-2024/
[88] ibid

accelerate innovation in the HVAC sector, prompting the development of new technologies and refrigerants that are less harmful to the atmosphere.

More 3D Printing[89]

3D printing continues to emerge as a transformative technology in the HVAC industry, particularly in producing ducting components. This technology allows for the creation of complex parts with precision and efficiency, which can lead to reduced waste and lower costs. For the HVAC industry, the adoption of 3D printing means the ability to produce custom parts on demand, reducing the need for large inventories and enabling quicker responses to specific customer needs.

The flexibility is a significant advantage for both manufacturers and service providers. It allows for more personalized solutions, potentially shortening repair and installation times for customers. The impact of 3D printing extends to sustainability efforts as well. 3D printing contributes to the industry's environmental responsibility by minimizing material waste and enabling eco-friendly materials.

Smart HVAC Expansion[90]

Smart HVAC systems are a rapidly growing segment within the industry, characterized by their integration with the Internet of Things technology. The systems offer advanced features like remote monitoring, automation, and enhanced energy efficiency, all increasingly in demand by consumers looking for convenience and cost savings. The expansion of smart HVAC accompanies a rising awareness of energy consumption and the need for more efficient climate control solutions.

Homeowners and businesses are seeking ways to reduce their carbon footprints and energy bills. Smart HVAC systems provide a solution by optimizing heating and cooling based on real-time data and user behavior. For the HVAC industry, the rise of smart technology signifies a shift towards more technologically advanced systems that require new skills and expertise. It also opens up opportunities for new services, such as ongoing system monitoring and data analysis, which can provide additional value to customers.

HVAC as a Service[91]

HVAC as a Service (HVACaaS) is an emerging business model in the market. It shifts the focus from one-time transactions to a subscription-based service, where customers pay for ongoing maintenance, repairs, and upgrades. The model offers a predictable revenue stream for providers and can lead to better system maintenance and customer satisfaction due to regular service. HVACaaS's impact

[89] ibid
[90] ibid
[91] https://www.motili.com/blog/upcoming-hvac-trends-2024

on the industry is significant. It encourages manufacturers and service providers to produce higher-quality, more durable units, knowing they will be responsible for their long-term performance.

For customers, HVACaaS means potentially lower upfront costs and the assurance of proactive service, which can extend the life of their HVAC systems and ensure more consistent comfort.

Increased Sustainability Efforts[92]

Increased sustainability efforts in the HVAC industry reflect a growing commitment to environmental responsibility and energy conservation. The green HVAC movement involves developing and using more energy-efficient systems with a reduced carbon footprint and utilizing renewable energy sources where possible.

For the HVAC industry, sustainability strategies mean innovation in design and the use of durable materials with less environmental impact. Green HVAC also involves adopting practices that contribute to the circular economy, such as recycling old systems and using refrigerants that are less harmful to the ozone layer.

It is clear that the industry's move towards sustainability is more than a trend; it is becoming a standard practice. The shift helps protect the environment and resonates with consumers increasingly making purchasing decisions based on sustainability.

IAQ Emphasis[93]

Indoor Air Quality has become a focal point in the HVAC industry, driven by increased awareness of the health implications of indoor pollution. Understanding and controlling common indoor pollutants can help reduce various health risks. HVAC systems are critical in managing IAQ by filtering out pollutants and ensuring adequate ventilation.

Strategies to address IAQ issues include using advanced filtration systems, incorporating air purifiers, maintaining proper humidity levels, and utilizing ultraviolet light technology to disinfect air streams. As the industry continues to innovate, the focus on IAQ is expected to develop more sophisticated HVAC systems that can provide better air quality without compromising energy efficiency. The trend will likely gain momentum as consumers become more health-conscious and regulations around IAQ become more stringent.

The trends and overall shifts in HVAC optimization are accompanied by emerging innovations in the equipment and its components. Some of the recent solutions are listed

[92] ibid
[93] ibid

below. While this is not a complete listing, it does demonstrate how the industry is moving in synch with the same design and performance demands that architects and other contributors to building design are having to address:

Movement-Activated Air Conditioning[94]

Engineers at MIT have come up with a new air conditioning design that utilizes sensors along aluminum rods hung from the ceiling. Movement then activates these sensors. In other words, the air conditioner only kicks on when people are present.

A motion-activated system seems like such a simple, ingenious idea that it's almost baffling it hasn't been tried before now. However, this kind of prototype is just one example of how future HVAC systems are going to be more compact and portable, helping to reduce both energy and utility costs.

Thermally Driven Air Conditioning[95]

Another design that's recently been implemented is thermally driven air conditioning. An Australian company named *Chromasun* has produced a low-cost alternative to traditional A/C units. It isn't a widespread technology yet, and it will likely be several years before this kind of design becomes widely available in the United States. However, thermally driven air conditioning is a system that uses solar energy and is supplemented by natural gas, making it a highly efficient and effective system.

In fact, the double-chiller design provides more cooling capabilities than any other system so far, and it eliminates electricity costs altogether.

On-Demand Hot Water Recirculator[96]

A U.S.-based company out of Rhode Island and other manufacturers offer "on command" pumps for a home's water lines, which allows cool water to be circulated back into the water heater upon activation. This product was engineered to be a solution to a major problem to which all of us contribute: Each year, the average home wastes 12,000 gallons of water just waiting for that water to warm up. Recirculating this otherwise-wasted water back into the system is an eco-friendly solution that's bound to play a huge part in future homes.

Ice-Powered Air Conditioning[97]

A California-based company has created an ice-powered A/C system called the Ice Bear. The Ice Bear essentially works by freezing water in a tank overnight, so the ice can help cool a building the next day. So far, the design has been able to provide enough cooling for a building for up to six hours, after which, a conventional

[94] BUILDER magazine: builderonline.com; "INNOVATIONS SHAPING THE FUTURE OF HVAC", by Paul Hill, January 23, 2018.
[95] ibid
[96]BUILDER magazine: builderonline.com; "INNOVATIONS SHAPING THE FUTURE OF HVAC", by Paul Hill, January 23, 2018.
[97] ibid

commercial air conditioner takes over. Although this type of technology has quite a way to go before it can be the sole cooling system for a home, six straight hours of cooling a commercial building is a solid step in the right direction.

Sensor-Enhanced Ventilation[98]

An ingenious product unveiled in 2015 consists of sensor-driven vents that replace a home's existing ceiling, wall, or floor vents. The best part? A smartphone app can control the *Ecovent*, providing precise, room-by-room temperature control. Additionally, the system utilizes sensors to monitor a home's temperature, air pressure, and other indoor air quality factors. Even though this system design is new, it's been well tested and has already hit the market. Therefore, this is one piece of technology you can take advantage of today.

Dual-Fuel Heat Pumps[99]

Several U.S.-based companies offer products that rely on the dual-fuel heat pump concept. The argument is that heat pumps tend to be more efficient and provide the maximum amount of comfort when using a combination of fuel. In this case, the system is a combination of an electric heat pump and a gas furnace. At low temperatures, the pump draws on gas heat to maximize efficiency. When the temperature rises above 35 degrees, electricity takes over. The initial costs associated with a dual-fuel heat pump are more than a conventional system, but the amount of money you can potentially save over the next several years more than makes up for the costs.

Geothermal Heat Pumps[100]

Along those same lines, geothermal technology is a major investment that promises to save the user much money over its lifetime. Geothermal heat pumps have been around since the 1940s, so they're not exactly a new technology. Nevertheless, these products haven't really caught on until recently.

With more homeowners waking up to the importance of going green, geothermal heat pumps have grown in popularity. A geothermal heat pump gets its energy directly from the earth through an underground looped pipe that absorbs the heat and carries it into the home. When cooling is needed, the process occurs in reverse, with the pump removing warmth in the home. A major bonus of having a geothermal heat pump is the availability of free hot water. Therefore, if you're considering having geothermal technology installed in your home, ask your technician about this valuable perk.

[98] ibid
[99] ibid
[100] ibid

Smart Homes[101]

Connected systems and phone apps now allow us to control our home's lighting, heating, cooling, security systems, surveillance, and entertainment at the push of a virtual button. It's a no-brainer that these "smart" technologies will continue to evolve and become integrated into our homes, allowing us to control a home's comfort levels down to the last detail. Since many of these innovations such as the Nest learning thermostat are already available on the market, this movement toward a smarter home has changed how HVAC engineers and designers approach the next big thing, which is good news for those of us who appreciate high-tech solutions.

Fully Automated Homes[102]

As if owning a smart home wasn't convenient enough, fully automated homes will soon become a reality. There are already technological solutions on the market that are allowing companies to experiment with automated appliances and other products. Therefore, it's only natural that HVAC systems will one day be directly tied into other systems in your home, making adjustments according to the status of the rest of the house.

Harnessing Heat from a Computer[103]

If you own a laptop and have used it for several hours in one setting, you know how much heat it begins to generate. One innovator named Lawrence Orsini, founder of Project Exergy, has seen how efficient computers are at generating heat. This is why he has theorized they can be used for powering heating systems. Harnessing heat from a product you already use every day is a smart idea. Why waste all that excess energy when you don't have to?

The systems and innovations discussed are in various stages of implementation and not all of them will likely gain widespread acceptance. The reasons for broad adaptation of any innovations are primarily driven by a broad felt need, a workable response, economics, and timing. Some great concepts simply are badly timed. Others are too expensive, But the right product at the right price and at the right time usually becomes common.

One of the factors that is likely to affect the selection of which HVAC products gain popularity in the coming years will have to do with how building designs are also morphing, and architects are re-engaging with their past and taking an increasingly active and involved role in HVAC selection and even design.

3.2. Architectural elements that influence HVAC systems.

[101] ibid

[102] BUILDER magazine: builderonline.com; "INNOVATIONS SHAPING THE FUTURE OF HVAC", by Paul Hill, January 23, 2018.

[103] BUILDER magazine: builderonline.com; "INNOVATIONS SHAPING THE FUTURE OF HVAC", by Paul Hill, January 23, 2018.

As has been presented in the foregoing discussions, the collective objective of all HVAC innovations and technological trends is to make the systems have a low or zero carbon footprint while still delivering the target of superior air quality, user comfort and functional performance. The mechanical systems and improved automation and fine-tuning of controls can go so far and at some point, the marginal benefits reach a point of diminishing returns – meaning the costs for incremental improvement is more than any benefit that is derived from it. This is not to discount these efforts but to highlight the fact that while these improvements continue, the big bang contributors should not be overlooked. These are the effects of the building design itself, a theme often repeated throughout this course. The elements of a building's design that affect the HVAC system design are:

- **Building size and perimeter configuration.** The shape of the building can affect HVAC design due to different exposures to solar heat gain and wind. Usually compact and simple designs with smaller surface areas yield more energy efficient results. However, simple or complex, if the architect designs with the local sun, wind and surrounding features in mind, the choice of the building's shape and surface treatments can have many positive knock-on effects for the HVAC system. To best achieve the optimal shape within the general design concept, architects can benefit from seeking early input and design suggestions. The good news is that such collaborations have begun to occur more frequently.
- **Building Orientation.** Building orientation describes a building's placement on a site and the positioning of windows, rooflines, and other features. A building oriented for solar design takes advantage of passive and active solar strategies. Passive solar strategies use energy from the sun to heat and illuminate buildings without the use of external energy sources and mechanical systems. Building orientation combined with the proper selection of building materials and the placement of windows, openings and shading devices influences heating and cooling loads, natural daylighting levels, and air flows within the building.[104]
- **Floor to floor heights** (if multi story) or floor to roof height (if single story). HVAC design is essentially a volumetric calculation. How those volumes are managed in the architectural design can make HVAC systems have a heavy or a gentle response. Control of unnecessary heights or reduction of treated volumes by lowering false ceilings can reduce the size and duration of HVAC use.
- **Building envelopes (walls & roof) efficiency**. The efficiency of a building's envelope determines how much heat gain or loss occurs and where it occurs (Thermal transmission). Thermal transmittance, also known as U-value, is a measure of how much heat flows through a building envelope per unit area and temperature difference. It is a key indicator of the energy performance and thermal comfort of a building. The U value is totally determined by an architect's choice of

[104] https://greenmanual.rutgers.edu/nr-building-orientation

materials – from the exterior face to the insulation, air gaps and interior face and finishes of the wall or roof system. Having an early agreement with the HVAC engineer and the owner of the U-value for walls and roofs can guide the proper material selections and set budgetary constraints.

[**NOTE**: "U" values sometimes get confused with "R" values. They are not the same. They are actually mathematical reciprocals of each other. A U-value is 1/R; an R value is 1/U. U-value (also known as U-factor) is a measure of heat transfer (heat gain or loss), while R-value is a measure of heat resistance. U-value is not a material rating; it is a calculation of the conduction properties of various materials used in the construction.[105]] When considering these values, the following are simple things to remember:

- **Higher numbers** are good when comparing the Thermal Resistance and **R-Values** of products.
- **Low numbers** are good when comparing **U-Values.**
- The U-Value is the most accurate way to judge a material's insulating ability, taking into account all the different ways in which heat loss occurs, however it is more difficult to calculate.

The goal of architectural envelope designs should be to achieve as low a U value as feasible within the design budget. This combined with other adjustments to heat gain like shading devices can lower the demand on the HVAC system.

- **Interior materials and insulation.** The choice of building interior materials, insulation in interior walls, the types of ceilings, window treatments and exhaust systems all have an effect on the performance of an HVAC system. Too often it is perceived that once the exterior envelope is optimized, the architectural design has done its part in assisting the HVAC performance. But it is just as important, and in large building footprints, even more so, that the designs of the interior area separations be given careful consideration. In some cases, code determined area or fire separations create sub zones within a building that have to be managed independently by an HVAC system. In these cases, the separations are essentially another "exterior" type of demarcation requiring control of thermal transfer and control of air infiltration. Similarly, there are building types where it is functionally required to ensure air from one area does not go into another so differential pressures have to be maintained. In other types of spaces such as laboratories and clean rooms, the purity (free from dust or other micro particles) of the air is so critical that special filtration (HEPA filters) are used and often the air cannot be recirculated and hence has to be exhausted at every air change. These situations

[105] https://www.stanekwindows.com/u-value-vs-r-value

have to be managed jointly between the architect and HVAC engineer to find ways to minimize the size of the areas that need such controlled environments and the extra load imposed on the mechanical systems. Air locks or other isolation features can be used by architects to minimize peripheral leakage and thus help enhance the controlled area's effectiveness while reducing HVAC system load.

Typically, interior walls are not insulated unless there is an acoustic reason to do so. However, if there are areas of more use than others or areas where the disparity between heat generation or utilization is great, it is good practice to insulate the separation so "waste" heating or cooling is not done in an area which may not need it. This is true of many buildings where the HVAC system is not highly compartmentalized (zoned) or where individual room control is not feasible. Much of this decision making is an economic one to gauge the benefits of the initial added cost of insulation against any HVAC system cost savings in equipment size and future operating savings.

The treatment of interior floors and ceilings also affects how an HVAC system performs. It has been noted previously that ceiling heights can be reduced by minimizing volumes. For example, a carpet won't generate heat, but it will raise the ambient temperature of the room. It does this by insulating the room against the floor and helps keep the warmth that's already inside the room, bouncing around instead of sinking below the floor.[106] On the flip side, hard tile materials are best for keeping a space cool. For example, marble tile is one of the best conductors of heat, making it an excellent cooling tile for warm weather climates.[107]

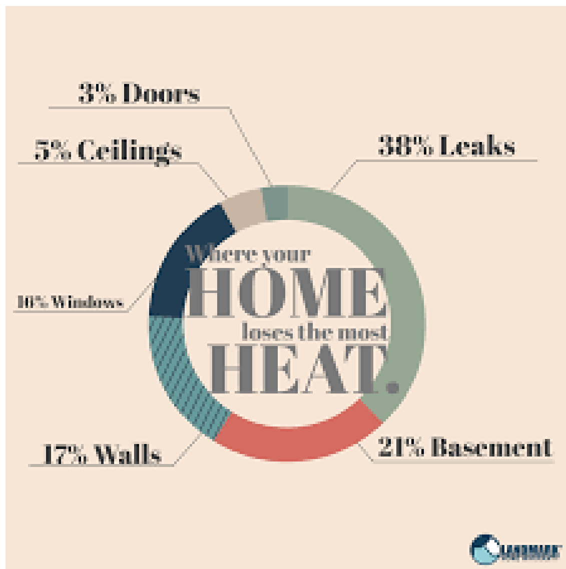
As with floors, similar principles apply to ceiling treatments. For example, acoustic ceiling tiles can help to reduce energy costs by improving the insulation of a room. They can help to keep a room warm in the winter and cool in the summer, reducing the need for heating and air conditioning.[108] In the context of ceilings, the shape also contributes to the warming or cooling properties of a space. For example, vaulted or domed shapes help with cooling while flatter surfaces are better at trapping in heat. Another architectural system that helps with managing air is the use of Climate Ceiling.

Climate ceilings are a unique and innovative approach to indoor climate control. Unlike traditional HVAC solutions, these regulate temperature by providing both the necessary cooling during the summer months and the desired heating in winter. They can distribute warm or cool air evenly across an entire room, promoting a uniform indoor climate. In addition, thanks to their sound-absorbing capacities, climate ceilings are ideal for high acoustic comfort, which is also crucial when looking to enhance well-being. And by minimizing the need for bulky ducts, grilles,

[106] https://www.easipaycarpets.co.uk/does-carpet-make-home-warmer
[107] https://floorauthority.com/blogs/inspiration/cooling-tile-flooring
[108] https://sound-zero.com/complete-guide-to-acoustic-ceiling-tiles

and other unsightly mechanical components, they result in more usable space and a sleek aesthetic that blends seamlessly into any interior design.[109]

- **Sealing cracks, joints, seams.** The greatest amount of air infiltration or loss of heat/cooling occurs from the seemingly smallest "defects". According to one study, around 38% of heat loss in your home comes from cracks in your walls, windows and doors (often invisible to the naked eye). In fact, a ⅛ inch gap under a 36-inch wide door will let as much cold air into your home as a 2.4 inch hole through your wall.[110]



[111]

This is an area where proper detailing of joints, material transitions and application of the right sealants at joints is very critical and falls squarely in the architect's domain. One of the downsides of overreliance on HVAC systems to provide effective indoor comfort has been that many aspects of building design details get less attention. Recent emphasis on energy consumption and a generally more environmentally aware outlook has brought these issues into much sharper focus.

3.3. Design considerations (passive and active) that help an HVAC system.

Throughout this course material, many concepts and techniques have been discussed from historical methods to more recent technology reinforced ideas. Many of these can be classified as "passive" while others are "active". To better classify an approach, it is useful to provide a basic definition for these terms as they are not universally standard. How these

[109] archdaily.com/996751/climate-ceilings-combining-thermal-acoustic-and-visual-comfort
[110] landmarkhw.com/resources/hvac
[111] ibid

terms are used depends on context and topic. For the purposes of discussing passive design in terms of HVAC optimization, this course is using the following understanding:

> **Passive design** maximizes the use of 'natural' sources of heating, cooling and ventilation to create comfortable conditions inside buildings. It harnesses environmental conditions such as solar radiation, cool night air and air pressure differences to drive the internal environment. Passive measures do not involve mechanical or electrical systems.[112]
>
> **Active design** makes use of active building services systems to create comfortable conditions, such as boilers and chillers, mechanical ventilation, electric lighting, and so on. Buildings will generally include both active and passive measures.[113]
>
> **Hybrid systems** use active systems to assist passive measures, for example, heat recovery ventilation, solar thermal systems, ground source heat pumps, and so on. Very broadly, where it is possible to do so, designers will aim to maximize the potential of passive measures, before introducing hybrid systems or active systems. This can reduce capital costs and should reduce the energy consumed by the building.[114]

To help optimize and make an HVAC system more effective, the main objectives remain, as previously mentioned:

- Minimize energy consumption.
- Minimize the load that the HVAC system must manage.
- Maximize natural resources.
- Integrate Architectural design to require mechanical augmentation only as necessary.

The above objectives are achieved by maximizing passive design considerations, so the active intervention is kept low.

So, to reduce energy consumption, passive design strategies use ambient energy sources instead of purchased energy like electricity or natural gas. These strategies include daylighting, natural ventilation, and solar energy. Properly insulate and air seal your home. Select an energy-efficient heating system that doesn't use electricity.[115]

To best impact the HVAC system, the following building design strategies will reduce the load on the HVAC system:

- Orientation.
- Massing.
- Shading.

[112]designingbuildings.co.uk/wiki/Passive_building_design
[113] Ibid
[114] ibis
[115] Energy.gov; "Reducing Electricity Use and Cost"

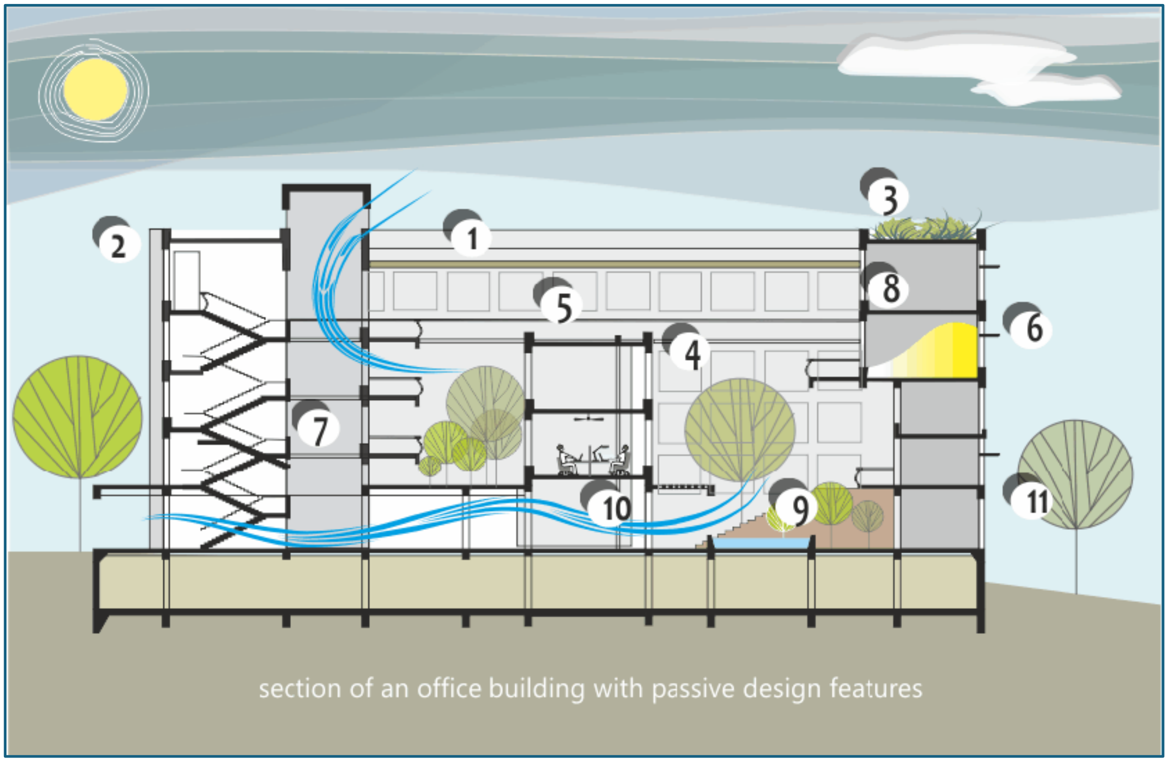
- Landscape.
- Green roofs.
- Material selection (encourage local materials).
- Thermal mass.
- Insulation.
- Internal layout.
- The positioning of openings to allow the penetration of solar radiation, visible light and for ventilation.

In its simplest form, a shallow building orientated perpendicular to the prevailing wind with openings on both sides, will allow sunlight to penetrate into the middle of the building and will enable cross ventilation. This should reduce the need for artificial lighting and may mean that cooling systems and mechanical ventilation are not necessary. In taller buildings, stack ventilation can be used to draw fresh air through a building, and in deeper buildings atriums or courtyards can be introduced to allow light into the center of the floor plan.[116]

The above strategies may not always work or be practical as articulated but the principle is to think through these during the design process to see which can be practical and economical. It is rare that none can be used.

As has been shown, most passive design relies heavily on taking advantage of natural elements and resources. The simplified illustration below illustrates how passive elements can be incorporated into a building design:

[116] designingbuildings.co.uk/wiki/Passive_building_design



SOURCE: net zero energy buildings *(https://nzeb.in/knowledge-centre/passive-design)*

LEGEND:

1	Overhangs on the south façade (in the northern hemisphere -north façade in the southern hemisphere)
2	Fins for shading the west façade (depends on building location)
3	Green roof
4	High performance glazing
5	Roof insulation over decks
6	Lightshelves for daylighting
7	Openings for natural ventilation
8	Thermal mass
9	Water body for evaporative cooling
10	Thermal comfort
11	Vegetation (Landscape) for sun control

In a March 2023 article published on NOVATR (https://www.novatr.com/blog/passive-design-architecture-examples), author Saumya Verma captured several examples of buildings that have successfully implemented passive design principles and achieved both design excellence and performance advantages. The article is worth exploring because the buildings range in variety of size, function and location – illustrating how the principles are adaptable globally.

- Himurja Office Building, India.
- Ha Ha Haus, Australia.
- Sheikh Khalifa Medical City, Abu Dhabi, UAE.
- Max House, India.
- The Crystal, London, England.
- Bosco Verticale, Milan, Italy.
- Eastgate Center, Zimbabwe.
- Earth Tower, Vancouver, Canada.
- School of Environment and Design, Singapore.
- Masdar City, Abu Dhabi, UAE.

What these projects illustrate is that Passive design is not intended to eliminate HVAC systems but, when intentionally incorporated into the architectural design, it can enable more efficient and HVAC designs with much lower carbon footprints and greater user comfort. Coincidentally, these projects also dismiss the myth that incorporating passive design elements limits or inhibits design creativity. On the contrary, it allows greater design expression – and that with a rationale that is not merely aesthetic. In fact, it is over reliance on mechanical systems that has perpetuated a global glut of steel and concrete box buildings that have no relationship to or engagement with the environment in which they are built.

3.4. HVAC consultant and architect – developing joint design strategies.

At this point it is, hopefully, clear that optimization of HVAC systems and optimization of architectural design, or, for that matter, any other component of the built environment, are all interconnected and are most successful when all parties work in collaboration. To draw upon an overused analogy to a symphonic composition that is best when every musician is on the same sheet of music.

In the context of this course, it has been posited that after the emergence of mechanical systems and the convergence of urban growth, architects and HVAC engineers became increasingly siloed in the work they did. The role of the HVAC engineer, for the most part, became one of sub-contractor rather than a design partner. Fortunately, recent shifts in how architecture and related design and planning professions are reexamining their roles, has created an opening for a genuinely collaborative approach – akin to a design partnership rather than a purely contractual relationship. An advantage in how HVAC design is delivered in the United States and many other countries is that HVAC, Electrical and Plumbing and, often, fire protection are provided collectively by a MEP (Mechanical, Electrical and Plumbing) consultant. This already ensures that building piping, electrical (and fire protection) and HVAC systems are already integrated and coordinated in one entity. It is the relationship with the architect that has yet to evolve to the point of partnership.

While architects can achieve significant enhancements to a building's performance simply by more environmentally responsive designs just as MEP professionals can also achieve major efficiencies by simply continuing to tweak their systems and develop innovative arrangements and controls. But if both pool their expertise during the design phase of the building, the net gains will be greater than the sum of their individual contributions. The mechanisms and techniques to be used have been discussed or alluded to already. To best balance the proper needs and economics of the project, the following are ways in which architects and MEP design partners:

Communication: One of the biggest challenges facing architects and engineers is communication. Architects often work on the overall design of a building before passing it along to MEP engineers, who then need to integrate their systems into the design. This requires clear communication between both parties, as MEP systems must be seamlessly integrated into the design without compromising the aesthetics of the building. [117]

Early Collaboration: To achieve this, architects and engineers must work collaboratively from the early stages of a project. This means that architects should consider the technical requirements of MEP systems when designing a building, while engineers should be involved in the design process from the outset. By working together, architects and engineers can ensure that MEP systems are integrated into the building design in a way that is both functional, visually appealing, and deliberate. Another benefit of collaboration between architects and engineers is that it can lead to more sustainable and efficient buildings. MEP engineers can provide valuable input on designing a building to minimize energy consumption, reduce waste, and conserve resources. A simple conversation regarding building orientation, glazing, and shading can greatly impact building upfront costs as well as long-term operational costs.[118]

Joint Accountability: Any contractual relationship is always fraught with an element of adversity and caution. The focus is on working to a defined scope and protection against liability. While these are sound business principles, in trying to achieve a collaborative or partnership type of engagement these can be a hindrance as an MEP consultant may be reluctant to venture into advising on design lest they assume any liability for an adverse outcome. Similarly, an architect may fear challenging an HVAC design or venturing alternate solutions lest they take on the responsibility for its performance. These concerns inhibit open exchange and

[117] Gleason Engineering: "The Importance of Collaboration Between Architects and Engineers". April 10, 2023

[118] ibid

restrict discussion to however the contract was worded, and fees arranged. The way around this dilemma is either to have flexible contracts where the scope, while defined, should not restrict options discussions and the liability and responsibility clauses need to allow for joint responsibility for design solutions that are implemented in collaboration. Another approach is for Architectural firms to establish formal partnerships with MEP firms that would simplify contractual and compensation issues on a project-by-project basis. This arrangement also creates long-term understanding by each party of the other's preferences, styles, and clientele, allowing for a well-coordinated and tailored responses. Finally, a practice that is emerging is for architectural firms to have their own dedicated MEP divisions with the MEP engineers working as employees of the architectural firm. The opposite is also true where engineering firms specializing in industrial work will employ architects on their payroll. In the past these were arrangements of convenience but, as clients have become more design savvy, and requesting more responsible design solutions, staff engineers or architects are becoming equal members of their respective organizations.

3.5. HVAC optimization and Sustainability.

Optimization in any industry is an ongoing process and one that is always present due to competition in the market. For most of the 19th and 20th centuries, optimization in the HVAC field was primarily driven by these economic drivers. The chlorofluorocarbons (CFC) ban coming out of the Montreal protocol was the first major regulatory force that caused major innovation and coupled with the simultaneous emphasis on energy conservation, directed efforts for optimization and innovation towards what has now come to be broadly termed as "sustainability".

Before listing out how HVAC optimization and sustainability intersect, a brief examination of HVAC optimization is needed:
HVAC systems optimization has two lanes: systems; and environmental. The "systems", as the name suggests, is focused on making the systems themselves as efficient and high performing as technically possible and economically relevant for a given project. The environmental or external, is to determine the best systems and solutions for the optimal results for the building, its design and its end users.

Systems optimization, the solution must automatically control HVAC equipment as a holistic system 24/7 so that it uses the least amount of energy without sacrificing performance. It's impossible to judge a solution's optimization capabilities without first understanding the three laws of optimization[119]:

[119] optimumenergyco.com/how-to-optimize-an-hvac-system

- Measurement comes first. Without an accurate measure of energy use by each piece of equipment, it's impossible to accurately predict and report the impact of varying conditions on the entire system. If you can't measure it, you can't optimize it.
- Optimize systems, not just individual components. If an optimization plan focuses only on installing the most efficient pieces of equipment or saving energy in one subsystem without considering how to maximize the performance of the whole system, it will fail to capture the total available efficiency potential.
- Optimization must be automatic, dynamic, and continuous. To achieve maximum efficiency, optimization must be a real-time dynamic process, not a static set-and-forget process. Operational control must be automatic and based on real-time inputs and adjustments.

When optimization fails to meet expectations, it's often because the solution couldn't deliver closed-loop optimization in real time. Products sold as being able to "optimize" vary widely, from efficient components to component-based efficiency tools to systemwide HVAC optimization. Because no standard definition for "HVAC optimization" is guiding the industry, engineers often don't get the energy and cost savings they expect from the products they specify.[120]

Environmental or external optimization. This is the aspect that deals with design collaboration with architects and the discussions on the right mix of passive and active solutions. This is also where the impact on the environment and sustainability is most commonly measured.

> Sustainable HVAC design falls under both interior environment and energy-performance categories. The interior environment factors are closely linked to American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) 62-1999 and ASHRAE 55-1992, with additional emphasis on individual controls and HVAC-system monitoring. Many building codes also base the design of mechanically ventilated occupancies on ASHRAE documents, so those buildings with compliant design receive basic credit.[121]
>
> It is important to note that some codes allow operable windows instead of a mechanical ventilation system in certain occupancies, which, in extreme climates, reduces indoor-air quality to an unacceptable level. Other sustainability goals promote the use of operable windows and the possible

[120] optimumenergyco.com/how-to-optimize-an-hvac-system
[121] CONSULTING SPECIFYING ENGINEER: " Sustainable HVAC Strategies"; by David Toshio Williams, P.E., LHB Engineers and Architects, Duluth, MN. February 1, 2001

elimination of major mechanical systems. However, assuring acceptable air quality requires more engineering. It is in the energy-performance category that the most dramatic gains in efficiency, and thus sustainability, can be realized.

Basic system selection and equipment sizing affect energy consumption to a great degree. According to a recent study, oversized HVAC equipment and a lack of lighting controls are among the top three missed opportunities to save energy in commercial buildings.[122]

Good design does not mean overdesign. The majority of mechanical/electrical devices and systems perform at their best when selected near their maximum capacity. If future capacity is desired, it is wise to plan for this, especially to take advantage of improvements in technology and performance to the greatest extent possible.[123]

Considering that air conditioning contributes about 4% of all global greenhouse gas emissions[124] and some studies suggest this may rise 25% of the total by 2025, it is imperative that efforts continue to both make the systems more sustainable but also to engage in design practices that reduce the usage. This becomes even more urgent when Net Zero is factored in – this aims to achieve zero net emissions by 2050. This is in direct contradiction to where most projections suggest the need for cooling (air-conditioning) is headed. It is already imperative that a manifold improvement in both technological advances in HVAC technology and a dramatic shift in social and urban design attitudes will be needed to optimize the global contradiction for both a climate controlled and a sustainable environment.

3.6. Integrating architectural and HVAC optimization seamlessly – back to the future.

Section 3.4 dealt with the ways architects and HVAC engineers (MEP engineers) can and should collaborate if the collective goal is to design better, environmentally friendly, and efficient buildings. If "good" progress is made in that direction, it is reasonable to expect that the current negative trends in terms of greenhouse gas emissions can be reversed. The operative word in the preceding sentence is "good". This would mean that at least collaboration between MEP and architects becomes the norm rather than purely a sub-contract relationship. It would also mean that codes will become more stringent in terms of emissions. Finally, the "good" progress is not possible if owners and society do not engage in demanding (or, at least, asking) for sustainable design. For that to happen, the design solutions and mechanical systems will have to strike balances that are economically

[122] ibid

[123] CONSULTING SPECIFYING ENGINEER: " Sustainable HVAC Strategies"; by David Toshio Williams, P.E., LHB Engineers and Architects, Duluth, MN. February 1, 2001

[124] WASHINGTON POST: "How air conditioners will have to change in the future", by: Shannon Osaka, June 9, 2023.

viable. This is the current dilemma – good, sustainable design is generally more expensive, and the economics drives development towards the cheaper solution. According to The Online Code Environment and Advocacy Network (OCEAN), “green” buildings cost, on average, 2.5% ~ 7% more than similar conventional buildings and can yield up to 20% savings in life cycle costs. One would think this would be a no brainier. However, this value proposition is a hard sell mainly because the 7% is an up-front capital cost while the savings are spread out over a long time and subject to proper maintenance and diligent use – not necessarily bankable and consistent practices.

In order to strike the right balance, architects will have to travel back in the past to see how human comfort was achieved prior to air conditioning and then refine those solutions with current and future technologies to make them more efficient. The proverbial wheel was invented millennia ago but with each new bearing and tread design, it gets better. Architects need to go back to the wheel instead of relying on HVAC to essentially drag a flat tire through brute force. Similarly, HVAC engineers will have to reimagine their role as not just to solve every problem through MEP systems but to also go back to the past and see how older solutions may have beneficial utilization in future in the right place and circumstance.

This course started with a discussion about the pre-industrial considerations for human comfort. Those considerations have not changed, the means to address them have and, in some cases, the solutions have created and/or compounded the problems – such as urbanization, abandonment of natural elements in design and overcrowding. Some of these are unintended consequences, others have different root causes (for example, economic drivers) but all are interrelated, and MEP systems are facilitating all this. This is not to propose that modern cities be abandoned, and everyone return to a rural setting. That would be absurd and the opposite of sustainable. The goal forward is to learn from the best of the past and fix what can be fixed, ensure that new communities are developed on the right footing and as old systems break down, replace and repair with better, more sustainable products.

Architects and MEP professionals can and should advance the best sustainable and optimized strategies to their clients. But, in the end, until society is willing to back up its desire for clean and sustainable buildings and communities with a willingness to make the necessary adjustments, achieving a sustainable HVAC target for Net Zero will remain a growing challenge.

This concludes Part 3 of the course.

Part 3 Review Questions

21. To incentivize manufacturers to make products as energy efficient as possible, in 1992, the US Environmental Protection Agency (EPA) introduced ___________________________, as a voluntary labeling program.

a. Montreal Protocol
b. Net Zero
c. ENERGY STAR
d. None of the above

22. Are operable windows universally allowed by building codes?

a. No, they are not permitted under any circumstances.
b. Yes, they are universally allowed.
c. No, they cannot be used if the building has air conditioning.
d. Yes, some codes allow these instead of a mechanical ventilation system in certain occupancies.

23. What is HVACaaS?

a. An energy rating service that promotes HVAC systems with an efficiency star rating.
b. HVAC systems that have 3D printed components.
c. It is also known as "Sensor Enhances ventilation".
d. It is an emerging business model that shifts the focus from one-time transactions to a subscription based service for HVAC services.

24. Which of the following statements is not true?

a. Passive design is not intended to eliminate all HVAC systems.
b. Reliance on Mechanical systems has not had any meaningful impact on the glut of steel and concrete box buildings.
c. If both (architects and MEP professionals) pool their expertise during the design phase, the net gains will be greate4r than the sum of their individual contributions.
d. Contractual relationships are fraught with an element of adversity and caution.

25. Each year, the average homes wastes _____________ gallons of water just waiting for that water to warm up.

a. 3,000
b. 5,000
c. 7,000
d. 12,000

26. Thermal Transmittance, also known as ____________________ is a measure of how much heat flows through a building envelope per unit area and temperature difference.

a. U-value
b. R-value
c. AC value
d. All of the above

27. It is important to seal cracks, joints, and seams. According to one study, around ______ % of heat loss in your home comes from cracks in your walls, windows and doors (often invisible to the naked eye).

a. 25%
b. 33%
c. 35%
d. 38%

28. According to The Online Code Environment and Advocacy Network (OCEAN), "green" buildings cost, on average, 2.5% ~ 7% more than similar conventional buildings and can yield up to ______________savings in life cycle costs.

a. 10%
b. 15%
c. 20%
d. 25%

29. In this course, what is MEP an acronym for?

a. Mechanical, Electrical, and Plumbing
b. Mechanical, Electrical and Pumps
c. Minimize, Electrical and Pumps
d. Meters, Electrical and Plumbing

30. According to the author of the course, is there any value in looking at pre industrial building design to improve designs for the future in the 21st century?

a. No. The past created the problems that future technology must solve.
b. No. Buildings did not have any comfort prior to air conditioning.
c. Yes. Looking back to the past to see how human comfort was achieved without mechanical systems and then refine those solutions with technology.
d. Yes. Technology has created all environmental problems, and the solution is to revert back to exclusively natural solutions.

Part 1 Review questions:

1. **Within the AQI index, what numbers are considered Good?**
   a. 301-500; incorrect, this AQI score is considered Hazardous
   b. 201-300; incorrect, this AQI score is considered Very Unhealthy
   c. 101-150; incorrect, this AQI score is considered Unhealth for Sensitive Groups
   d. 0-50; correct, this AQI score is considered Good

2. **Which of the following is considered one of the five major pollutants established by the EPA (and regulated by the Clean Air Act)?**
   a. Carbon monoxide, Correct
   b. Nitrogen dioxide, Correct
   c. Ground-level ozone, Correct
   d. All of the above, Correct; ground-level ozone, particle pollution, carbon monoxide, sulfur dioxide and nitrogen dioxide are the five major pollutants established by the EPA.

3. **The zone for a comfortable ambient space generally ranges from a temperature of _______________.**
   a. 60°F to 85°F; incorrect
   b. 65°F to 75°F; correct - However, this range can vary depending on season and climatic zone. In the United sates, we generally use guidelines provided by The American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc (ASHRAE) when designing for building air comfort. The ASHRAE guidelines consider their recommendations for a majority of building occupants wearing a normal amount of clothing while working at a desk. These guidelines recommend 68ºF to 74ºF (20ºC to 23ºC) in the winter and 72º F to 80º F (22º C to 27º C) in the summer.
   c. 63°F to 75°F; incorrect
   d. None of the above - incorrect

4. **The ASHRAE guidelines recommend a relative humidity (RH) of _______________ when designing for building air comfort.**
   a. 20 – 40 percent; incorrect, RH should be 30 – 60 percent
   b. 30 – 70 percent; incorrect, RH should be 30 – 60 percent
   c. 30 – 60 percent; correct, In addition to temperature, Relative Humidity (RH) is also an important factor in air comfort. RH (expressed as a percent), often just called "humidity", measures water vapor, but RELATIVE to the temperature of the air. In other words, it is a measure of the actual amount of water vapor in the air compared to the total amount of vapor that can exist in the air at its current temperature. The ASHRAE guidelines recommend a relative humidity (RH) of 30 to 60 percent.
   d. 50 – 70 percent; incorrect, RH should be 30 – 60 percent

5. **Which of the following are elements of Passive Cooling?**
   a. Shading devices; correct
   b. Use of light colors to reflect heat; correct
   c. High ceilings; correct
   d. All of the above; In addition to Wind catchers to redirect ventilation, Orientation of windows to enable cross ventilation, Use of thick walls for insulation, Use of water elements to cool air flow and provide psychological calming.

6. **Robert Griggs and Joseph Nason pioneered the art of heating buildings by steam and came up with a radiator system using vertical iron tubes in:**
   a. 1843; incorrect
   b. 1863; correct, In the second half of the 19th century, cast iron radiator systems became hugely popular in America. Three manufacturers of those radiators merged to become the American Radiator Company. Radiator based central heating started to fade out by the mid-20th century as combination air-conditioning and heating systems began to take over.
   c. 1883; incorrect
   d. 1903; incorrect

7. **Which of the following are pollution related effects of HVAC systems?**
   a. Energy consumption – leading to greenhouse gas emissions.; correct
   b. Materials used in Air Conditioning units; correct.
   c. Unclean ducts, correct
   d. All of the above; correct - also included is Ozone depletion in addition to all listed effects of HVAC systems.

8. **______________________ designed an apparatus that not only controlled humidity but also cooled the air. His invention featured an intricate system of coils and fans that circulated cooled air through the space.**
   a. Franz San Galli; incorrect
   b. Joseph Nason; incorrect
   c. The American Society of Heating, Refrigerating, and Air Conditioning Engineers; incorrect
   d. Willis Carrier; correct, This breakthrough invention formed the basis for Carrier's later innovations and eventually led to the establishment of the Carrier Air Conditioning Company in 1915

9. **The first residential air conditioner was installed in what year?**
   a. 1902; incorrect; air conditioning was "invented" in 1902
   b. 1914; correct; the unit was enormous at 20 feet long and 7 feet high. In 2022's money, it would have cost 500,000.
   c. 1931; incorrect, in 1931 a comparatively more affordable option was introduced in the form of a window unit. This made air conditioning more commonplace.
   d. 1900; incorrect

10. **The main pollution related impacts of HVAC systems is/are:**
   a. Ozone Depletion; correct - Old AC systems should be disposed of properly because they may contain chlorofluorocarbons that can harm the ozone.
   b. Energy Consumption; correct - Air conditioning units consume a lot of energy, creating pollution in the form of greenhouse gas emissions.
   c. Materials Used in Air Conditioning Units; correct - Air conditioning units are made of various materials that may damage the environment.
   d. All of the above; correct – Energy Consumption, Ozone Depletion, Materials Used in Air Conditioning, and Unclean Ducts are the main pollution related impacts of HVAC systems.

<u>**Part 2 Review Questions**</u>

11. **Ventilation is the management of air flow through an interior space. Ventilation can be achieved in a building by ________ methods.**
   a. 2; incorrect
   b. 3; correct, Ventilation is achieved by three methods – natural, mechanical and combinations (mixed mode)
   c. 4; incorrect
   d. 5; incorrect

12. **_____________ are conduits or passages used in heating, ventilation, and air conditioning to deliver and remove air.**
   a. Ducts; correct - The needed airflows include, for example, supply air, return air, and exhaust air. Ducts commonly also deliver ventilation air as part of the supply air.
   b. Condenser; incorrect - A compressor is a mechanical device that increases the pressure of a gas by reducing its volume.
   c. Evaporator Coil; incorrect - An evaporator coil is the opposite of the condenser coil, most often located on the top of the indoor unit box.
   d. Filter; incorrect - A filter is the porous component of the HVAC system that helps to trap dust particles, allergens, and other impurities present in the air that gets into your house. It purifies the air, making it safe to breathe.

13. **What applications is a Multi-Split system ideally suited for?**
   a. Small commercial spaces like retail shops.; incorrect
   b. Retrofit of old historic buildings; Incorrect
   c. Large or complex commercial buildings like hotels or office complexes.; correct; Multi-split systems are best suited for larger commercial spaces, such as office buildings, hotels or retail complexes, where multiple rooms or zones require individual temperature control and a single outdoor unit is preferable.
   d. Single family suburban homes; incorrect

14. **Geothermal systems are incredibly _______________ and environmentally __________, with _____ costs…**
   a. Expensive, harmful, high
   b. Powerful, friendly, moderate
   c. Energy-efficient, friendly, low operating
   d. Safe, sustainable, low

15. **The ______________ is a crucial part of an HVAC components diagram and is designed to control or regulate airflow within the HVAC System.**
    a. Chiller; incorrect, A chiller is a machine that removes heat from a liquid coolant via a vapor-compression, adsorption refrigeration, or absorption refrigeration cycles.
    b. Combustion Chamber; incorrect - Often called a burner, the combustion chamber is the component of the HVAC system that allows the air to be heated up.
    c. Damper; correct - It may be used to regulate airflow in ducts, VAV boxes, chimneys, or air handlers. It is quite helpful in cutting off airflow to unused rooms.
    d. Vent; incorrect - Air passes from the duct system into rooms via metal vents. These are made of a material that resists hot and cold temperatures. Located on or close to the ceiling, AC vents usually have movable slats that control airflow and the amount of cooling/heating a room receives.

16. **The _____________________ is the component of the HVAC the user interact with the most and controls the heating and cooling units based on preferred settings.**
    a. Humidifier; incorrect - The humidifier, a vital HVAC component, adds moisture to indoor air using water or steam. This enhances comfort and occupants' health while preventing dryness, static electricity, and damage to woodwork and furniture.
    b. Boiler; incorrect - The boiler is a part of the HVAC system responsible for heating the water or the steam.
    c. Filter- incorrect - - A filter is the porous component of the HVAC system that helps to trap dust particles, allergens, and other impurities present in the air that gets into your house. It purifies the air, making it safe to breathe.
    d. Thermostat – correct - The thermostat lets you adjust your HVAC system's temperature, fan speed, mode, and schedule. Different types of thermostats, including manual, programmable, and intelligent, offer additional features and benefits.

17. **What is the difference between an Air Handler and a Chiller?**
    a. An Air Handler absorbing heat from the indoor air, as the furnace blower blows warm air over them while a Chiller adds moisture to indoor air using water or steam
    b. An air handler, or air handling unit (often abbreviated to AHU), is a device used to regulate and circulate air as part of a heating, ventilating, and air-conditioning (HVAC) system while a Chiller is a machine that removes heat from a liquid coolant via a vapor-compression, adsorption refrigeration, or absorption refrigeration cycles.
    c. An Air Handler regulates the temperature at which air is blown into a space while a Chiller regulates water flow into the Air handler.
    d. They are synonymous terms.

18. **For basic project design data, which of the following is considered information that an HVAC engineer would obtain from an architect?**
    a. Project location; correct
    b. Building perimeter size, number of stories and interior volumes; correct
    c. None of the above; incorrect
    d. Both a & B; correct, there is a lot of data that HVAC engineers can solicit from architects to include both a & b as well as; Ambient climatic conditions at the location, Project performance requirements, Building orientation; shelter in place requirements, available area for HVAC equipment and more…

19. **What determines the right size of equipment needed to keep the interior temperature comfortable while using as little energy as possible?**
    a. Options evaluation and Stylistic Considerations; Incorrect, these discussions will include how the proposed system will work with the building layout, site implications for exterior equipment and access and maintenance facilitation of roof and ceiling mounted equipment.
    b. The Load Calculation; correct - The goal of an HVAC load calculation is to determine the right size of equipment needed to keep the interior temperature comfortable while using as little energy as possible. This type of calculation takes into account factors such as insulation, window areas, and the number of occupants in each room. It also considers regional climate conditions like temperatures, humidity levels, and wind speeds.
    c. RCP and Fixture Selection; incorrect, Once the HVAC engineer has determined their design solution and identified duct sizes, supply and return air zones, thermostat placements and other features of the HVAC design, all of these decisions are generally documented on the RCP (Reflected Ceiling Plan), architectural drawing that forms the basis for coordinating physical locations of HVAC supply and return air registers, vents, lighting and the general ceiling configuration.
    d. Basic Project Design Data; incorrect - This is the general site and building design data that helps an HVAC engineer assess the building needs in terms of the environment where the building is situated and what limitations of space and building design concept will have to be overcome.

20. What was banned as a result of the Montreal protocol?

a. Carbon Dioxide – incorrect
b. Ozone – incorrect
c. Chlorofluorocarbons (CFCs) ; correct – Countries came together and ratified the Montreal Protocol which went into effect in 1987 and banned CFCs. This is cited as one of the most successful international environmental laws ever.
d. All of the above - incorrect

Part 3 Review Questions

21. To incentivize manufacturers to make products as energy efficient as possible, in 1992, the US Environmental Protection Agency (EPA) introduced ____________________________, as a voluntary labeling program.
a. Montreal Protocol; incorrect - The seriousness of this issue and the direct link to the CFCs led to the adoption of what became known as The Montreal Protocol.
b. Net Zero; incorrect - Net zero refers to the balance between the amount of greenhouse gas (GHG) that's produced and the amount that's removed from the atmosphere. It can be achieved through a combination of emission reduction and emission removal.
c. ENERGY STAR – correct - The Energy Star label is found on more than 75 different certified product categories, homes, commercial buildings, and industrial plants. In the United States, the Energy Star label is also shown on the Energy Guide appliance label of qualifying products.
d. None of the above

22. Are operable windows universally allowed by building codes?

a. No, they are not permitted under any circumstances.
b. Yes, they are universally allowed.
c. No, they cannot be used if the building has air conditioning.
d. Yes, some codes allow these instead of a mechanical ventilation system in certain occupancies.

23. What is HVACaaS?

a. An energy rating service that promotes HVAC systems with an efficiency star rating.
b. HVAC systems that have 3D printed components.
c. It is also known as "Sensor Enhances ventilation".
d. It is an emerging business model that shifts the focus from one-time transactions to a subscription based service for HVAC services.

24. Which of the following statements is not true?

a. Passive design is not intended to eliminate all HVAC systems.
b. Reliance on Mechanical systems has not had any meaningful impact on the glut of steel and concrete box buildings.
c. If both (architects and MEP professionals) pool their expertise during the design phase, the net gains will be greate4r than the sum of their individual contributions.
d. Contractual relationships are fraught with an element of adversity and caution.

25. Each year, the average homes wastes _____________ gallons of water just waiting for that water to warm up.
a. 3,000; incorrect
b. 5,000; incorrect
c. 7,000; incorrect
d. 12,000; correct - A U.S.-based company out of Rhode Island and other manufacturers offer "on command" pumps for a home's water lines, which allows cool water to be circulated back into the water heater upon activation. This product was engineered to be a solution to this major problem.

26. Thermal Transmittance, also known as ____________________ is a measure of how much heat flows through a building envelope per unit area and temperature difference.
a. U-value; correct - . It is a key indicator of the energy performance and thermal comfort of a building. The U value is totally determined by an architect's choice of materials – from the exterior face to the insulation, air gaps and interior face and finishes of the wall or roof system.

b. R-value; incorrect - "U" values sometimes get confused with "R" values. They are not the same. They are actually mathematical reciprocals of each other. A U value is 1/R; an R value is 1/U. U-value (also known as U-factor) is a measure of heat transfer (heat gain or loss), while R-value is a measure of heat resistance. U-value is not a material rating; it is a calculation of the conduction properties of various materials used in the construction.[125]]
c. AC value; incorrect
d. All of the above; incorrect

27. It is important to seal cracks, joints, and seams. According to one study, around _______ % of heat loss in your home comes from cracks in your walls, windows and doors (often invisible to the naked eye).

a. 25%; incorrect
b. 33%; incorrect
c. 35%; incorrect
d. 38%; correct

28. According to The Online Code Environment and Advocacy Network (OCEAN), "green" buildings cost, on average, 2.5% ~ 7% more than similar conventional buildings and can yield up to _______________savings in life cycle costs.

a. 10%; incorrect
b. 15%; incorrect
c. 20%; Correct
d. 25%; incorrect

29. In this course, what is MEP an acronym for?

a. Mechanical, Electrical, and Plumbing
b. Mechanical, Electrical and Pumps
c. Minimize, Electrical and Pumps
d. Meters, Electrical and Plumbing

30. According to the author of the course, is there any value in looking at pre industrial building design to improve designs for the future in the 21st century?

a. No. The past created the problems that future technology must solve.
b. No. Buildings did not have any comfort prior to air conditioning.
c. Yes. Looking back to the past to see how human comfort was achieved without mechanical systems and then refine those solutions with technology.
d. Yes. Technology has created all environmental problems, and the solution is to revert back to exclusively natural solutions.

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	Poor		⟷		Excellent
1. Overall satisfaction with this course	1	2	3	4	5
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How could these courses be improved?

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What other topics would be of interest?

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