

# Traditional and Innovative Cooling Systems

Energy efficient, alternative strategies  
for thermal comfort

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Fig. 1 Ancient wind towers, or badgir, in Dubai

### Introduction

The cooling of spaces to enhance human comfort is not a modern idea (Figure 1). However, the exploitation of physical and chemical properties of refrigerant fluids to transfer thermal energy is a fairly recent human accomplishment, traceable to several experiments conducted in the 19th century.<sup>1</sup>

The first modern, electric air conditioner (AC) was the invention of Willis Haviland Carrier in 1902.<sup>2</sup> Since that time we have come to take for granted that a building will be equipped with an air conditioning system, and few have an understanding of AC paradigms and technologies beyond that of a conventional, electrically operated unit.

In this section we first describe some fundamental features of conventional AC technology. Then we explore innovative strategies and AC system types that use alternative forms of

energy, while making more efficient use of the electricity they do require.

### Conventional AC systems

The conventional choice for a building AC is a *vapor compression* (VC) system. Compared to other system types they are much more widely marketed, and they run solely off a standard source of electricity. They are relatively inexpensive to install because they require little equipment, and they are available in cooling capacities that will serve the entire spectrum of need, from a single room to a large building. Furthermore, they are a very mature technology that has seen significant improvements in efficiency over the past few decades.

One such measure of efficiency is the *coefficient of performance* (COP), defined as the ratio of thermal energy transferred by an AC system to the amount of input energy required. It is not uncommon for a

residential AC system to have a COP of 4 or greater.<sup>3</sup>

In a VC system, a refrigerant fluid is first induced to evaporate by being injected from a tube of high pressure to another of very low pressure. Lower pressure on a liquid means a lower boiling temperature, so that the molecules evaporate readily. Also, evaporation means that the fluid molecules take on energy, thereby cooling their surroundings. Traveling to the compressor, the gaseous fluid is now forcefully driven into an adjacent high pressure tube. This compression keeps the pressure in the first tube low, maintaining the process of evaporation at the other end. The refrigerant is now cooled with air or water, and at this high pressure it is more inclined to condense, sloughing off the thermal energy it gained by evaporation. The liquid then returns to the starting point to begin the cycle again.

Commonly used refrigerants for VC systems have changed over the years, primarily because of discovered dangers to human health and the environment. Even today the most common refrigerant in a conventional VC system is R-22, a hydrofluorocarbon with a global warming potential 1800 times that of carbon dioxide.<sup>4</sup> In the US, R-22 will be phased out of use in new equipment in 2010, and out of use altogether by 2020.

As we realize that we must reduce our carbon footprint and address other environmental concerns, we begin to question the implications of the fact that much of our electricity is generated by inefficient processes that have dramatic environmental impacts. We see that we must

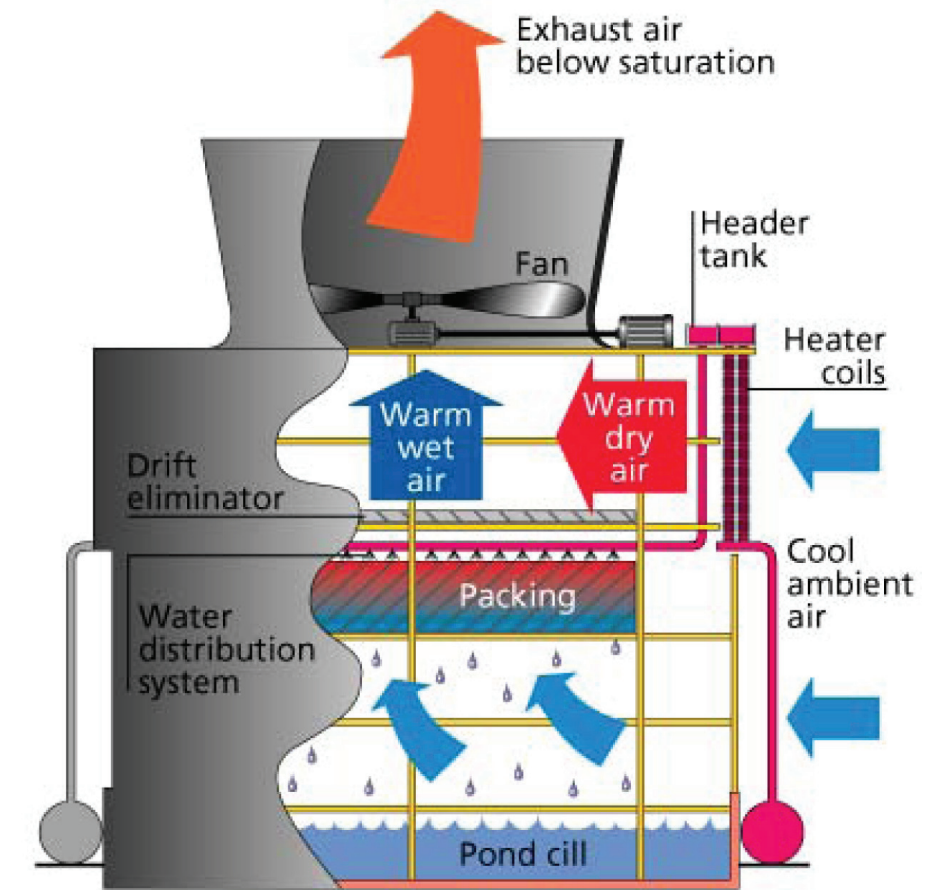


Fig. 2 Water is cooled in an open system through evaporative cooling.

consider new ways of thinking about AC systems, and we see the value of exploring alternative AC technologies that use much less electricity, because they are driven by other energy types.

In what follows, we first consider an innovative way of thinking about how we cool air—a *district cooling* system. Then we describe several AC technologies that are driven by thermal energy, and which might serve as alternatives to a conventional VC system. Finally, we describe several geothermal cooling systems

that might be appropriate in certain contexts.

### District Cooling

District cooling is an efficient method of transferring energy, in this case by chilling water, at a central location to be distributed to a network of customers. A central water chilling plant “eliminates the need for separate systems in individual buildings.”<sup>5</sup>

District cooling is most effective where there is a concentration of cooling loads, such as universities,



Fig. 3 District cooling tower in downtown Austin, 3rd & San Antonio

“industrial complexes, densely populated urban areas and high density building clusters.”<sup>6</sup> When planning area development to take advantage of district cooling, it is also possible to retrofit current buildings to use chilled water.

In a typical district cooling plant, water is chilled through evaporative processes within a cooling tower. Heat is emitted when water is pumped to the top of the tower then allowed to flow down through plastic or wood shells (Figure 2).<sup>7</sup> In open/direct cooling towers such as those found on the UT campus, water is allowed to come into contact with the outside air. While pollutants may enter an open-loop system, a closed-loop system is available, which cools the air by more indirect means.<sup>8</sup>

Austin has two downtown chilling plants, which can chill water to 44 deg-F (Figure 3). This water is then piped to various buildings and into their refrigeration coils, where fans cool the building by blowing air over the cooled coils. Austin’s downtown cooling plants are a 33,000 ton capable system, with ample capacity to service “future mission critical”

cooling developments.<sup>9</sup> The system typically runs at night, when energy load and demand are lowest, to meet peak demand with “enough [energy] to equal the demand of 4,500 homes.”<sup>10</sup>

Other Austin District Energy locations include the Domain (with the “nation’s first packaged modular CHP [Combined Heat and Power] plant to exhaust heat directly into an absorption chiller”), and the Mueller Energy Center, considered among “the most environmentally friendly energy systems in the world.” Beyond district cooling, the Mueller CHP also provides steam heating and onsite electricity production.<sup>11</sup>

District cooling eliminates the need for multiple, less efficient systems in individual buildings in favor of a single, larger system in a central location. With the infrastructure thus located off site, noise level in a building is lessened, and no space needs to be allocated for a cooling unit. The only disadvantage to such a system is the possibility of system failure, in which case a single incident prevents many buildings from operating.

### Thermally Driven Cooling Systems

Recently, AC systems that are driven by thermal energy have gained attention, not because they are necessarily newer than VC technology, or even because they have a higher COP. The advantage of a thermally driven system is that much of the needed energy may be collected and stored from readily available sources. Though natural gas is a common source of the required heat, solar thermal energy or even waste heat from co-generation may be used, both of which represent environmen-

tally friendly alternatives to the use of generated electricity.

### Absorption and Adsorption Systems

Two alternative AC technologies resemble the VC system in that they induce evaporation of a contained liquid refrigerant. The fundamental difference is that either *absorption* (the uptake of a gaseous coolant into a liquid medium) or *adsorption* (collection of molecules onto the surface of a collecting medium) replaces condensation to keep pressure low in the chamber. These systems then require an additional step to recover the refrigerant in a liquid state, and this is where thermal energy plays a role.

#### Absorption systems

Among solar heat driven AC technologies distributed in Europe, absorption systems are by far the most widely used, with 59 percent of the European market of this type.<sup>12</sup> Two chemical pairs are most common: ammonia absorbed into water, or water absorbed into a strong lithium bromide (LiBr) and water solution.

The water/LiBr solution illustrates the process well. First, liquid water in a chamber devoid of air boils readily and fills the void because of the low pressure. This extracts heat from the container walls and cools the space outside it. At the other end of the low pressure tube, a strong LiBr/water solution absorbs the vapor, weakening in the process, but maintaining evaporation in the first chamber.

The weakened solution then moves to another chamber, where it is heat-

ed to increase pressure and cause much of the water to evaporate. This vapor then passes into another chamber, where it is cooled by water under high pressure. This induces condensation and a return to a lower temperature, so that the water may begin the cycle again.

Absorption chillers have until recently only been available for large scale applications 50kW and above (Figure 4). However, systems appropriate for residential scale buildings are becoming available (down to 5kW).<sup>13</sup> Wang notes that the main problems with the LiBr technology on a small scale are cost and reliability.<sup>14</sup> Henning notes that “the main obstacles for large scale application, beside the high first cost, are the lack of practical knowledge on design, control and operation of these systems.”<sup>15</sup> Furthermore, these systems require water heated to 88 deg-C or higher, “which is not in good match with building solar integrated heating systems.” There is also a potential for the lithium bromide to crystallize.<sup>16</sup>

An ammonia/water absorption system is cheaper to produce and maintain, but not as effective as the LiBr/water system. Also, it requires an expensive solution pump, which is significant expense for a smaller scale system. Furthermore, ammonia is toxic, so the danger of refrigerant leakage becomes a significant consideration.<sup>17</sup>

#### *Adsorption systems*

“To date, only a few Asian manufacturers produce adsorption chillers.”<sup>18</sup> In Europe this system type represents only 11 percent of the market share for solar driven air conditioners.<sup>19</sup> Still, adsorption AC technology



Fig. 4 Absorption chiller – Rethimno village hotel - Crete

has features that make continued research and development worthwhile.

An adsorption AC resembles an absorption system in that liquid refrigerant (in this case water) is induced to evaporate under low pressure and extract thermal energy from its surroundings (Figure 5). But instead of being absorbed into another fluid, the water vapor is adsorbed onto a bed of silica gel. A typical system has two such beds, and at any point in the system cycle, one is adsorbing water vapor while the other is being heated to regenerate a saturated bed. Once the former is saturated and the latter is dry, the roles are switched.

Adsorption systems have several advantages. One is that there is no potential for crystallization of a chemical salt like lithium bromide. Since

there is no internal solution pump, the system uses a minimal amount of electricity. Also, water is the refrigerant, so there are no harmful effects to human health.<sup>20</sup>

Compared to other AC types, however, adsorption systems are comparatively large and heavy.<sup>21</sup> Because they typically have a low COP, an adsorption system would require large solar collector area. Also, because they require a cooling tower and a hot water tank, the initial cost of such a system is high.<sup>22</sup>

#### **Closed versus open AC systems**

All three of the AC types described above are *closed* systems. The refrigerant fluid circulates in a closed loop and does not come into direct contact with the intake air. In fact, it is common for absorption and adsorption systems to chill water,



Fig. 5 Adsorption chiller - Sarantis - Greece

which makes them well suited for district cooling. Thus the architectural impact of an AC system on a building tied into district cooling can be minimal.

In contrast, an *open* AC system uses the water content of the intake air as the refrigerant. Such a system is especially appropriate in a hot and humid climate, for it addresses both the heat of the intake air and its high moisture content. A closed system cannot directly address excessive humidity in this way, and thus the typical closed system must cool the intake air to a temperature well below the comfort level to induce condensation of excessive moisture, and then reheat the air to bring it back into the temperature comfort range.

The most common open AC types are desiccant cooling systems, and these represent 23 percent of the European market share of alternative AC technologies.<sup>23</sup> Currently on the market is a system that employs a slowly rotating desiccant wheel, though a liquid desiccant system will be marketed in the near future.

#### *Desiccant wheel systems*

In a desiccant wheel AC system, intake air passes over a rotating wheel coated with silica gel or other desiccant material onto which the moisture content of the air is inclined to adsorb (Figure 6). Because adsorption represents a significant drop in energy level of the water molecules, and because this dehumidification is almost adiabatic (with no loss or gain of total thermal energy content), the dehumidified air is significantly hotter than before.



Fig. 6 The installed solid desiccant air conditioning unit in Kish Island

At a different point in the system, return air from the conditioned space is injected with water vapor to cool it. The hot, dry air and the cold, damp air then pass through a heat exchanger to cool the intake air. Before it is sent into the conditioned space, the intake air is re-humidified to lower its temperature further and bring its relative humidity back up into the comfort range. As the saturated parts of the wheel continue to rotate, collected thermal energy is then applied to desorb the water that was extracted from the intake air.

Desiccant wheel systems consume very little electrical energy, and are well suited to the use of waste heat. They are especially appropriate for humid climates, as they give much greater control over humidity levels than VC systems. Because they use no harmful refrigerants, they are environmentally friendly. They also may improve indoor air quality over other systems because of their high air exchange rate.<sup>24</sup> The systems are typically very reliable and easy to maintain. However, the architectural impact of a desiccant wheel AC system is significant, because it requires a large air handling unit.<sup>25</sup>

#### *Liquid desiccant systems*

Another desiccant cooling system, close to market introduction, uses a water-based solution to extract moisture from the intake air.<sup>26</sup> This system is more effective at dehumidification than the desiccant wheel; however, some of the potential issues for this system type are corrosion caused by the desiccant salts (calcium chloride or lithium chloride) and possible carryover of the liquid desiccant into the intake air. Figure 7 illustrates the expansive space



Fig. 7 Liquid desiccant cooling system, installed at the new "Solar Building Innovation Center (SOBIC)" at Freiburg (D).

required to accommodate such a system.

#### *Comparison*

Figure 8 illustrates the comparative features of the different thermally driven cooling systems. If such a system is to be powered by collected solar energy, the required collector area is illustrated in Figure 9.

#### **Geothermal Cooling**

Geothermal cooling uses the earth as a heat sink by cycling liquid through a buried loop pipe system. This releases the liquid's heat into the ground while cycling the newly cooled liquid back into the building. Typically called a *geothermal heat pump*, geothermal cooling uses 25%-

50% less electricity than conventional units.<sup>28</sup> Whereas outdoor temperatures fluctuate throughout the year, ground temperatures four to six feet below the surface remain relatively constant throughout the year.<sup>29</sup>

Like ancient bath houses that used springs to heat the waters, geothermal energy has been used for centuries and is extremely efficient. Geothermal systems are most appropriate for those who want design flexibility (zones), a reduced heating/cooling system footprint, and reduced environmental impact.<sup>30</sup> However, while the interior footprint is reduced, a larger one is created on the land.

In addition to the efficiency of the product (chilled water/solution), the







Method	Closed cycle		Open cycle	
	Solid	Liquid	Solid	Liquid
Refrigerant cycle	Closed refrigerant cycle		Refrigerant (water) is in contact with the atmosphere	
Principle	Chilled water		Dehumidification of air and evaporative cooling	
Phase of sorbent	Solid	Liquid	Solid	Liquid
				
Typical material pairs	water - silica gel	water - lithium bromide ammonia - water	water - silica gel, water - lithium chloride	water - calcium chloride, water - lithium chloride
Market available	Adsorption chiller	Absorption chiller	Desiccant cooling	Close to market introduction
Typical cooling capacity (kW cold)	50 – 430 kW	15 kW – 5 MW	20 kW – 350 kW per module	
Typical COP	0, 5 – 0, 7	0, 6 – 0, 75 (Single effet)	0, 5 – >1	> 1
Driving temperature	60 – 90 °C	80 – 110 °C	45 – 95 °C	45 – 70 °C
Solar collectors	Vacuum tubes, flat plate collectors	Vacuum tubes	Flat plate collectors, solar air collectors	Flat plate collectors, solar air collectors

Fig. 8 Comparative features of four solar thermal air conditioner technologies

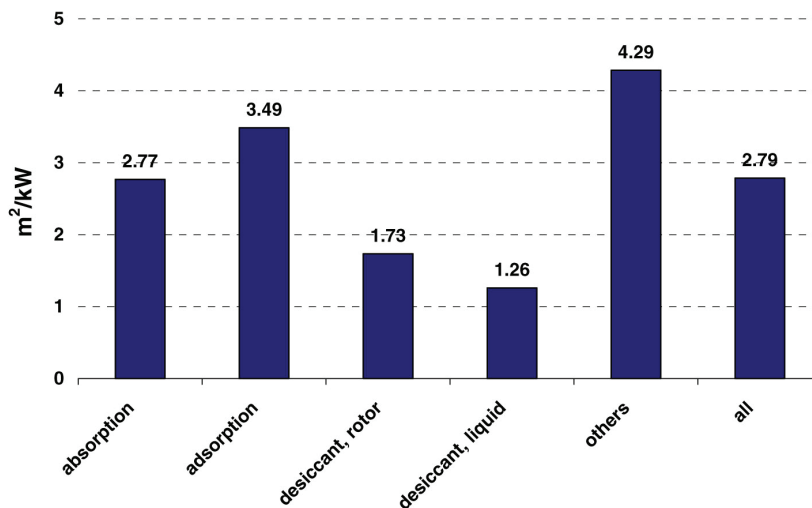


Fig 9 Required solar collector area in m<sup>2</sup> per kW of cooling capacity

hardware is also highly efficient. There are relatively few moving parts, and they are sheltered indoors, reducing maintenance and weathering and eliminating the need for an external compressor and fan. The piping can carry warranties of 25-50 years, and the pumps themselves can last more than 20 years.

Geothermal systems are classified as either *closed* or *open*. In a closed system the refrigerant liquid circulates repeatedly through the loop. In an open system, water is extracted from the ground and discharged at another location. Five types of geothermal loops are commonly used today: three closed-loop systems and two open-loop systems.

#### Closed loop systems

Closed geothermal systems typically use high density polyethylene pipe in one of three designs.

A horizontal loop installation (Figure 10) is the most common and most cost effective, yet requires larger land area than other systems. Trenches about four to six feet deep and running from 100 to 300 feet long are typically required.<sup>31, 32</sup> If a horizontal loop is chosen but the area of land needed is not available it is possible to coil the tube in the trench. This is not preferred, for it is less efficient due to interference with the overlapping tubes.

Vertical loop installation (Figure 11) is used when land use is limited, say in a retrofit application. This system involves holes bored about twenty feet apart and between 100 to 400 feet deep. Pipe is placed within the bored holes and then filled with a sealing solution that protects the pipes from weathering and corrosion, while increasing conductivity and heat transfer into the ground.<sup>33, 34</sup>

Pond and lake installation (Figure 12) requires a body of water, typically one-half acre in area and eight to ten feet deep, within 200 feet of the building. Coils of tubing are anchored to the bottom of the pond or lake. If the pond does not have an adequate volume of water, this may lead to more heat being introduced than can be dissipated. This causes overall warming of the pond or lake, and ultimately reduces the quality and efficiency of the system.

One additional closed loop system, a direct exchange method, is an older type of closed loop system. Instead of HDP pipes, it uses copper for better conductivity. Instead of a water-

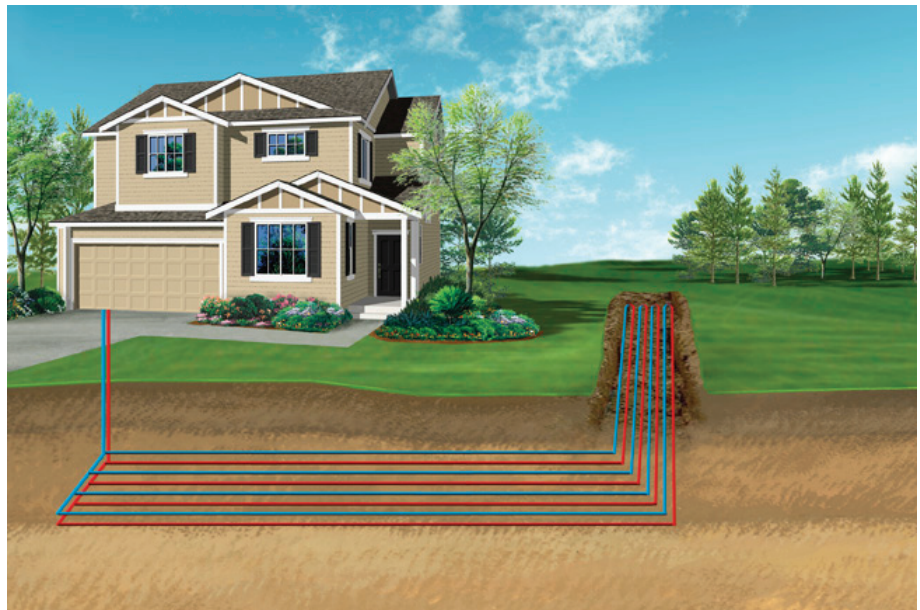


Fig. 10 Horizontal closed loop geothermal cooling system



Fig. 11 Vertical closed loop geothermal cooling system



Fig. 12 Lake/pond closed loop geothermal cooling system



Fig. 13 Lake/pond open loop geothermal cooling system

based liquid that is cycled through the pipe, a refrigerant is used which also increases the thermal conductivity. While direct exchange requires less pipe (one third to one half of a normal closed loop system) due to the efficient conduction of the copper pipe, the price per linear foot is significantly higher.

### Open loop systems

The two open-loop systems are essentially the same process, in that they extract water directly from the ground. However, the second system takes advantage of soil conditions and purposefully returns the water to a point near its intake.

The first open loop system brings water in and through the cooling system, and then returns it either back into the well or some other location (Figure 13). Guidelines dictate where this water can be properly discharged depending on its source, as well as how far the discharge zone must be so that discharged water is not reused too soon.

The second open-loop system is the *standing column* system. The process of taking in and discharging water is the same as the previous system. The difference is that a standing column system is designed to take advantage of bedrock conditions, so that cool water is pumped out from the bottom of the well, and the warmed water is discharged at the top of the well. As the water loses heat to the surrounding bedrock it sinks towards the bottom, cooling even more before it is pumped back through the system. Multiple standing column systems are common in New England states and can be found through out many boroughs of

New York City.<sup>35, 36</sup>

## Conclusions

Few circumstances will likely allow for easy accommodation of a passive cooling strategy such as a geothermal cooling system, especially for a building project of significant size or in a dense urban area. In this case, the architect is more likely to employ an active AC system in a new design project. To choose an appropriate thermally driven AC system, several variables must be considered: the scale of the project, the feasibility of a network for district cooling, the availability of solar or other source of thermal energy, and the climatic context of the project.

One early decision might be whether a centralized AC infrastructure can potentially serve the entire project as a distributor of conditioned air. If space permits this, then a desiccant wheel system would be a natural choice for a project in the Austin climate. In other circumstances, say where district cooling is desirable or where large air handling units are impractical, a closed absorption or adsorption system designed to chill and circulate water is probably a more natural choice.

## Notes

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## Figures

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