

# The impact of climate control technology upon the location of industries

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## Abstract

The major milestones in the development and commercialisation of refrigeration and indoor climate control (air conditioning) are identified. Examples are provided of its early industrial application in manufacturing and service industries such as theatres and shops. The innovations of Freon refrigerant gas in 1930 and the rotary compressor were the preconditions for smaller, automated units which were suitable for domestic use. Indoor climate control has subsequently become a major facilitator of economic activity and permitted the dispersion of industry location. It has also facilitated the application of computers which are reliant upon control of ambient temperature and humidity. The paper also discusses how climate control has facilitated move towards the sunbelt, and permitted the rise of cities such as Singapore, Dubai and Las Vegas. The ability to control indoor climate has led to all parts of the world being able to host industries which were otherwise climate dependent.

## Development of air conditioning and climate control

The modern system of air conditioning is a heat pump based upon the Rankine cycle. In this system, a gas is compressed which is then condensed, in the process removing the latent heat. The liquid then passes through an expansion valve, evaporating the liquid and drawing heat from the surrounding atmosphere. The gas is then compressed and the cycle starts again. The basic cycle was described by Carnot as early as the 1820s, but was refined by Rankine (1820-1870). This cycle also describes the heat processes which underlie the steam engine. (But not the railway locomotive which does not have a condenser.)

Like all theoretical thermodynamics, much engineering remained to be done in order to turn the cycle into a useful commercial product. The initial and obvious application was the preservation of food. Food had been kept cool using stored snow and ice for millennia and during the 19<sup>th</sup> century there was a brisk trade of ice from the NE of the US to places as far away as India. Improbable as it seems, the ice was insulated using natural materials and shipped in sailing ships, with still sufficient cold in it to be of use by the time it reached its destination. By the time refrigeration had been introduced, losses were as low as 8%. Cellars were also put to use to maintain cold temperatures.

Early refrigeration equipment was rudimentary and considerable advances were necessary in a number of engineering areas before the product had mass application. Some early installations (1860s and 1870s) relied upon air as the refrigerant gas, but its inefficiencies soon led to it being replaced with ammonia ( $\text{NH}_3$ ) or sulphur dioxide ( $\text{SO}_2$ ). Both of these had drawbacks as they were toxic or flammable at certain concentrations. Carbon dioxide ( $\text{CO}_2$ ) was used in ships, mainly for safety reasons. None of the compressors were electric; steam reciprocating compressors were generally used and plant required skilled technicians to operate. The various components such as compressors, expansion valves and evaporators were constantly being improved through the application of new materials and production techniques. Drawing upon the common usage of ice for cooling, the capacity of early plants was expressed in number of tons of ice per hour it could produce.

The earliest manufacturing application of refrigeration was in breweries, where productivity and quality control could be greatly increased if the temperature of the brewing vats could be controlled. Abattoirs and meat packing establishments were also early adopters. But as prices dropped and the application of temperature control became more widely appreciated usage expanded to include many process industries such as confectionary, gunpowder, oil refineries, paper, drugs, soap and so on. Commercial ice plants were also established to take advantage of the existing ice based infrastructure in homes and commercial establishments. By 1900, commercial refrigeration of food in warehouses was common.

The transport industries were also early adopters of refrigeration and in the case of Australia and New Zealand, the ability to freeze or chill products as diverse as meat, butter and fruit proved to be a great stimulus to economic

development. And, in a theme which will be expanded later in the paper, it permitted greater amenity in the warmer parts of the continent.

## Air conditioning

The earliest application of air conditioning, as opposed to refrigeration, was concentrated not upon cooling air but in controlling humidity. This was particularly relevant to industries where the product was hygroscopic, that is it drew moisture from the air. The first industry to make use of humidity control was textiles. Patents were taken out as early as 1904 for humidity control. This process was more complex than the refrigeration cycle. Whereas cooling the air could reduce humidity, increasing humidity, which was just as important for many processes, required an extensive system of water scrubbers and washers. This system could also act to clean and purify the air. This system of humidity control became known as *air conditioning*. However measuring humidity was a far more complex and inexact task than temperature measurement. Willis Carrier is the person most associated with this process.

Many different industries derived great benefit from humidity control. In addition to textiles, printing, food processing, paint, florists and nurseries, foundries and metal processing used humidity control. The ability to make climate irrelevant, had significant consequences for the location of industry. For instance, many textile mills in the US moved to the south closer to their source of cotton supply.

## Domestic refrigeration

Prior to the 1920s, domestic cooling of food was primarily by ice chest. Ice works and their attendant delivery infrastructure were prominent features of cities. Existing refrigeration technology favoured large and complex installations such as those found in industrial plants where high capital costs could be met, skill levels to operate the plant were available and the hazards associated with toxic refrigerant gasses could be managed. The high pressures associated with refrigerants such as ammonia also made size reduction to suit domestic premises difficult. Large houses sometimes used a split system where the compressor was placed in a basement and the refrigerant piped to where the cooling chest was.

The first technological innovation that underwrote small-scale refrigeration suitable for the home and small shop was the discovery of chlorofluorocarbon based refrigerant gasses (CFCs). These are still the refrigerant of choice in most applications. (They have been subsequently modified because of ozone layer damage.) The discovery of CFC, sometimes known as Freon, was made in 1930 by scientists at Frigidaire, the then whitegoods unit of General Motors.

The second innovation that permitted domestic application of refrigeration was the rotary compressor, introduced in 1928. Until then, compressors had been primarily the reciprocating type, using the same principle as a car engine only in reverse. The rotary compressor used an eccentric rotor and a stator with differing sized chambers to compress the refrigerant. This type of compressor could be scaled down more effectively, and was more efficient, than the reciprocating type. The necessary preconditions for domestic refrigeration had now been set and penetration of domestic refrigeration proceeded apace.

Air conditioning at its most basic level is technologically similar to a refrigerator so it is not surprising that attempts were made to adapt the basic technology to an air conditioning role. Primarily this took the form of window air conditioners, which were introduced in 1932.

## Humidity, temperature and human comfort

Prior to air conditioning, discomfort levels in public spaces were inhibiting many industries and activities. Parliaments and government offices in many of the northern capitals closed for months during the hot humid weather. Attending the theatre in summer became an endurance test and shoppers were reluctant to spend any more time than need be in department stores. The efficiency of public services such as hospitals and schools declined as humidity levels and temperatures rose. As a result, those involved in managing such activities were influenced to adopt the air conditioning practices used in industry.

The early terminology used to refer to this practice was comfort control. This indicates that it was not just temperature control that was being applied but also control of humidity. The air has two components which affect comfort, its temperature and humidity levels. The temperature is well known and fairly easy to measure. But humidity has probably a greater influence upon comfort.

Humidity is the amount of water vapour in the air, expressed as a percentage of the saturation point. As air becomes hotter, its capacity to hold water as vapour increases. 100% humidity means that water will not evaporate because the surrounding air is saturated. It is possible to exceed 100% humidity. In that case the air is “dripping”. Humidity is also influenced by air pressure, hence the “heavy” air before a thunderstorm. Hot air can carry far higher levels of humidity than cold air.

Comfort is of course relative and people do acclimatise. This process may be facilitated by architectural and building practices which mitigate the extremes of climatic variation, the “Queenslander” house being a typical example. Physiologists however claim that the ideal temperature and humidity levels for efficiency lie between 16-25 degrees Celsius and 20-40% relative humidity. (Sheridan 1963). Outside of this range efficiency in undertaking tasks may drop quite dramatically.

In most areas of eastern Australia we are familiar with the high humidity of the coastal areas and the discomfort it can cause. The moist north eastern sea breezes bringing high moisture content air from the ocean contributes to the problem. The tropics generally experience high humidity. But the arctic zones have the lowest humidity as the air temperature is so low it cannot carry any moisture. Antarctic air for instance is very desiccating.

In many areas of the world low humidity causes considerable health difficulties and discomfort. This is particularly so in colder climates where existing low humidity is exacerbated by heating the air, thus lowering the relative humidity. Low humidity can dry the skin and mucus membranes and cause eye problems. Aircraft are kept at 10% humidity, which is too low for long term comfort.

Lowering high humidity levels by chilling the air is comparatively easy. In conventional air conditioning, passing the air over the evaporator coils reduces its temperature and its saturation point. As the amount of water normally exceeds the saturation level at the lower temperatures, it is deposited as condensate. In home

air-conditioning this is a rough and ready but effective method of humidity control. Raising the humidity level is more difficult. In cold climates it requires water scrubbing and more complex installations. In homes, leaving bowls of water in a room is sometimes used.

Early moves towards air conditioning in public spaces, that is humidity and temperature control, originated in the United States, and focussed upon department stores and theatres. It was found that shoppers bought more when they were relaxed and did not suffer environmental stress. Also theatres had far greater patronage during the summer months. Stores and theatres which were air conditioned, widely advertised the benefits in their promotional material.

A word should also be added about air conditioners in motor vehicles. Drawing upon the technology of the rotary compressor and CFCs, it did not take long for air conditioning to find its way into busses, trains and other public conveyances. By the late 1930s, bus air conditioning was available but the system was too crude to be effective in smaller vehicles. Roof mounted refrigeration for transport was becoming more common in the 1940s, but the full application of air conditioning for motor cars had to wait upon techniques to miniaturise the system and the microprocessor to control it. By the 1960s it was becoming more common and is now almost ubiquitous in warmer climates.

## Enter the late modern age

By the 1970s, air conditioning and refrigeration had reached a mature stage of development where cost and technology were no longer significant barriers to widespread application. The electricity to drive the systems was readily available in most locations. Over the last twenty years, lower manufacturing costs in Asia have further reduced the price of air conditioning units. But as with its introduction, the main consumers of air conditioning are industrial and public establishments.

In this paper I wish to highlight three derivative effects of the ability to control climate. These are its contribution to the capacity to use computers, the drift to the sunbelt and the influence upon economic growth in tropical climates.

### Computers.

Computers need no introduction as a fundamental business tool. They provide the information needs of most industries and their usage is both ubiquitous and increasing. What is perhaps forgotten is that they are temperature sensitive and they generate considerable heat in their operation. And this heat needs to be removed from their immediate environment.

We are all familiar with the fan on our PCs cutting in and out as temperatures rise. This highlights the fact that computers act as resistors, and generate heat in their operation. All electricity which is consumed is converted into heat and must be removed from the ambient environment of the computer. The bigger the computer the bigger the problem! Supercomputers are often cooled by liquid nitrogen to lower their temperatures and thus resistance to electricity flows.

It would be impossible to use computers on a commercial scale in high temperatures without climate control and the ability to remove ambient heat and heat generated by the computer. Similarly humidity levels must be kept low in

order to minimise the effects of corrosion, deterioration of parts and electrical malfunction. PCs generally don't generate much heat so it remains a manageable problem. But on a commercial scale, climate control is necessary for their operation and has a symbiotic relationship with the computer.

Although this is applicable in all climates, it is of greater importance in the tropics. It means hot climate countries can compete on an equal footing for capital and industry, thus reducing climatic disadvantage.

## The drift to the sunbelt

Two countries which have extensive land masses which range from cooler to tropical climates are the United States and Australia. Both of these countries have experienced a considerable shift of population, if not industry, to the sunbelt states such as California, Texas and Florida. In Australia, Queensland, closely followed by Western Australia, has been the fastest growing state for some time. Although promoting its sunstate image, the reality is that much of Queensland is difficult to live in during the summer months; high levels of heat and humidity often make conditions enervating and uncomfortable. The parameters of the climate in many areas exceed what physiologists consider to be reasonable comfort levels. However the wide spread use of air conditioning in both workplaces and homes, alleviates much of the discomfort and the health threatening aspects of the climate. Thus a major barrier to population expansion and location of industry may be overcome.

Not everyone feels the need for air conditioning in the homes; only 62% of Queensland domestic dwellings are so fitted, but an increasing number do have two air conditioners or central air conditioning. But virtually all public buildings are air conditioned. Very few motor cars and public conveyances are not air conditioned.

## Location of industry

Linked loosely with the drift to the sunbelt is the influence which air conditioning has upon the location of industry. Modern industry is very dependent upon control of climate. From manufacture of pharmaceuticals and food through to office work and data processing, climate control is essential for efficiency, and for industrial processes, critical for the operation to occur at all.

Three examples will be briefly discussed; Singapore, Dubai and Las Vegas.

**Singapore:** Singapore experiences a tropical climate with both high temperatures and humidity. Morbidity for most of Singapore's history has been high, only declining once air conditioning became widespread, although this was not the only cause of expanding life expectancy. Traditional industry in Singapore was not climate dependent; it acted as an entrepot for the region and refined raw materials such as tin. The local architecture was designed for maximum natural cooling with the Straits Chinese shop house being common. This was a two story dwelling with a shop on the lower level. It had wide windows, generally with louvres for privacy and overhead fans were common. From the 1930s, air-conditioning started to be fitted in theatres. Refrigeration was also important for food and it is not accidental that the main chain of supermarkets in the region is called "Cold Storage". The

chain has its origins as an establishment founded in 1903, primarily to sell frozen Australian meat.

Fast forwarding to the present, we find that the majority of Singapore's main wealth generators are climate control dependent. Manufacture of pharmaceuticals and electronic components are high profile examples. But air conditioned office towers also dot the skyline and expatriates can locate to Singapore without extensive acclimatisation or risk to health. Public transport and most enclosed spaces are air conditioned and the split system domestic air conditioning is ubiquitous in building which are not centrally air conditioned.

**Dubai:** Dubai has a similar climate to Singapore although of course does not receive the rainfall. However the humidity can become high averaging 78% year round, rather a surprise for a desert location. Dubai has only come to world attention over the last twenty years as it has sought to become the entrepot linking east with west. In this it has been inspired by Singapore's role, including cloning its airline. (The airline Emirates is based in Dubai.) The population of Dubai previously spent most of the summer months of March to October building their activities around daytime temperatures which rarely dipped below 40<sup>0</sup> C. Clearly, such a climate is not the first one of choice for tourists, holiday makers and business people. However air conditioning isolated almost all activities from the ambient temperature. Dubai is now replete with high rises and enclosed spaces which isolate daily activities from the outside air temperatures.

**Las Vegas:** Las Vegas is well known as a casino and entertainment complex. Located in Nevada against the Californian border, it has a typical desert climate that ranges from very hot to quite cold, both diurnally and seasonally. In the summer months it also has very low humidity, with 11% relative humidity being common in summer afternoons. Such a desiccating climate is very poor for food handling, with the wilting of salads and the drying out of breads and other foods, not a process which tourists would appreciate. Las Vegas clearly does not have the natural climate to support the activities which comprise its economic base; it is only made possible by climate control.

Las Vegas has also been successful in attracting celebrities to live in the city whilst performing. Such celebrities take great care to look after their voices and find that the low humidity is a problem. Celine Dion reportedly maintains a constant 51% humidity wherever she is, be it car, residence or concert hall.

## Implication for economic development

The ability to control climate is a major contributor to the spread of economic growth. Cases such as Singapore and Dubai illustrate that economic activity need not be limited to ambient temperatures which can support such activity. From call centres in Bangalore through to through to textile mills in Egypt, climate control makes a major contribution to economic growth and renders climate almost irrelevant when locating industries. The cost of climate control is small relative to total costs and is rarely an issue as engineers and manufacturers have managed to reduce costs to a small component of total costs. Also when location of skilled personnel and expatriates is involved, the ability to provide homes which are insulated from the worst of the local climate, facilitates investment. Health issues,

which are often linked to high temperatures or the extremes of humidity, may also be controlled.

In this climate control may be seen to parallel that of our control of light. The use of electricity to disconnect activity from diurnal changes in light levels led to a significant increase in productivity. It is suggested in this paper, that climate control is acting in much the same way.

## Conclusions

This paper has made no attempt at analysing association through use of statistics. Rather it lets the major associations speak for themselves. The following are the major conclusion which may be drawn.

1. Technologies tend to rely on advances in a number of different areas. Air conditioning relies upon mass production, advances in machine tool capability, chemistry, availability of a suitable energy source, and so forth. Without advances in all of these areas, it would not be as widespread as it is today. This applies for almost all technologies.
2. Climate control has moderated the influence of climate upon location. The examples of Singapore, Dubai and Las Vegas, indicate that when considering location of industries, climatic conditions are considered a controllable variable. This has major implications for development as many poorer countries are located in areas of high temperature and humidity. It has also facilitated the growth of population in the sunbelt areas of the US and Australia.
3. It is difficult to predict long-term impacts of technology. Refrigeration started as aid to brewing and food preservation but the long term impact extends from underwriting major population shifts through to helping extend life expectancy. Often those technologies that lead to major societal changes are taken for granted and are rarely articulated; we are often drawn to concentrate upon the micro rather than the macro. Partly this is because the technological changes proceed incrementally without full appreciation of effects.
4. The refrigeration/air conditioning industry highlights how business is an agent of major change but it has little influence upon how that change evolves or how it affects society. This places it in a difficult position when business is involved in arguments which are more appropriately conducted in the political arena. A number of large businesses are now taking advice from ethnographers, anthropologists and others as to how their product is being used and how they are being integrated into social systems.
5. The case highlights the observation that new technologies take about 60 years to reach maturity, the point at which innovation slows considerably. For instance the first air conditioning patent was taken out in 1902, and by 1970, air conditioning was widely available and has not greatly changed since.

Similarly in industry, early applications of refrigeration were made in the 1870s, and by the 1930s the industry take-up was almost complete. Attempts have been made to use solar air conditioning using the absorption cycle but the cost differentials are actually increasing not decreasing.

## References.

Most of the information regarding dates and innovations in this case come from readily available sources on the internet. As most information is in the public domain extensive referencing of dates has not been undertaken. [www.carrier.com](http://www.carrier.com) provides the history of Carrier air conditioning, a pioneer in this field. [www.wikipedia.org](http://www.wikipedia.org) contains useful information on the emergence of refrigeration. [www.greatachievements.org](http://www.greatachievements.org) provides a useful potted history.

Books that have been found useful are:

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