Localised air conditioning: comfort with sustainable energy demand

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ABSTRACT: Emissions from rapidly expanding use of room air conditioning in emerging economies is likely to increase global temperatures by 0.5 °C by 2100. However global greenhouse emissions need to be eliminated by 2045 – 2055 to stabilize warming at 1.5 °C. To meet this requirement, an affordable, alternative, low-energy, low emission technology needs to be deployed on a mass scale within 25 years. Since new technologies typically take 30 – 40 years to deploy globally, it will be easier with technologies that are available now.

Experience demonstrates that small portable air conditioners (spot coolers) with appropriate air delivery technology can meet this need. They create a localized micro-climate for up to three people providing acceptable comfort using only 180 – 300 Watts. They work in any building with no requirement for installation, piping, draft sealing, insulation, or structural modifications. They also work outdoors in sheltered locations.

For sleeping in extremely hot conditions, a specially designed bed tent retains a layer of conditioned air above a bed and provides protection from biting insects. Air delivery is designed to create sufficient air movement past exposed parts of the head and neck of users to gain about two degrees of additional perceived cooling, enhancing comfort sensation.

KEYWORDS: sustainability, localized air conditioning, energy, emerging markets, comfort.

1. Need for low energy air conditioning solutions

Air conditioning, backed up by almost unlimited electricity generation capacity in the USA, triggered the economic transformation of the hot and humid south of the country (Gordon, 2000). Large populations in emerging economies, including most of Africa, South Asia and other hot and humid low income regions are seeking similar benefits and air conditioning usage is increasing rapidly. However, the use of 20th century room air conditioning technology for this would require an enormous and unsustainable expansion in electricity generation capacity and unacceptable greenhouse emissions. Recent estimates suggest that direct emissions from refrigerant loss and indirect emissions from power generation for residential room air conditioners using conventional technology will add 0.5 °C climate warming by 2100 (Campbell, Kalanki, & Sachar, 2018; Isaac & Van Vuuren, 2009). Air conditioning solutions are needed requiring 5-10 times less energy and refrigeration technology with negligible emissions. The 2018 update from the UN Intergovernmental Panel on Climate Change (IPCC) demonstrated the need to *eliminate* global greenhouse emissions preferably by 2045, no later than 2055 (Allen et al., 2018). This timescale limits solutions to technologies ready to deploy on a mass scale in the next twenty years.

Uncontrolled installation of conventional air-conditioners in emerging economies has already crippled electricity grids, necessitating frequent load shedding, and significantly raising the cost of electricity in most of the poorest regions of our planet. Most of the additional cost is indirect. For example, women have to obtain fresh food every day: the leftovers cannot be put in the fridge because the power is intermittent and unaffordable if battery backup or generator power supplies are used instead. Excess food uneaten by people has to be discarded or fed to animals at much greater cost than normal animal feed. Other indirect costs include limited employment opportunities due to higher business costs, more frequent equipment failures and lower operating efficiency. Throughout much of Africa and South Asia, also in many parts of Indonesia, regular one or two hour power interruptions are normal, often occurring several times during the day and night. 10-15 hour interruptions are not infrequent.

In many low-income countries, the electricity grid was originally installed and supported by low interest loans from the World Bank on generous terms, enabling governments to provide very low cost electricity. Later, as the infrastructure has had to be upgraded or replaced and fuel costs have risen, governments have been unable to foster a social consensus to raise electricity prices enough to keep the systems running. As supply quality has fallen, more and more people default on bill payments: politicians, government employees and other powerful figures simply ignore power bills even if they receive them. Meter tampering and bypassing have become commonplace. As maintenance resources become more and more inadequate, new connections are made in disorganized ways that make it easy to install additional undocumented and illegal connections.

One of the most significant factors, however, has been adoption of room air conditioners. In Pakistan, for example, it is estimated that air conditioners draw between a third and half of the peak summer demand for electricity. Governments are desperately seeking ways to install more generation capacity to meet this demand, and the financial consequences for low-income countries are crippling their economic development. Currently the Pakistan government is spending 1-2% of GDP on power subsidies and related costs, with no allowance for infrastructure replacement.

Few if any buildings in low-income countries are insulated and a large air temperature and humidity reduction is required for comfort. If air room conditioning is used, the running cost of an air conditioner is much higher than in the industrialised world. Almost all the energy is used to counteract heat and humidity entering the building through openings, walls, floors, and ceilings. Typical South Asia buildings stabilize with indoor temperatures around 40 – 42 °C for about six months. Air conditioning is a necessity in many areas for up to 10 months a year.

Figure 1. Split air conditioner fitted to uninsulated brick building in Lahore (2016: outdoor unit can be seen at far left side)

There is little chance of developing alternative room air conditioning technologies that could be deployed on a mass scale soon enough to meet IPCC requirements. Campbell *et al* (2018) concluded that there are no existing technologies, and the typical time to deploy new technologies on a global scale is 30-40 years. All current room air conditioning technologies require highly insulated, low thermal mass, draft sealed buildings to achieve energy reduction targets. There is no reasonable possibility that all the current buildings that do not meet these requirements can feasibly be replaced in a short enough time to meet IPCC emission reduction requirements.

There are solutions on the technological horizon, but these cannot feasibly be deployed quickly enough. Solar and geothermal powered absorption cycle technology is feasible in some locations, but requires large up-front capital investment and reconstruction of existing buildings. Membrane dessicant technology is being developed at the National Institute of Standards in the USA. Phase change materials absorb heat effectively, reducing the energy needed for mechanically driven room air conditioning. It is taking time to refine these technologies sufficiently for commercially feasible operating results, and it is unlikely these technologies can be deployed on a mass scale well before 2055.

Indirect evaporative cooling also offers large energy reductions, particularly in drier climates. This technology can be used to cool hot outside air without increasing the moisture content, yet still exploiting the latent heat absorbed by evaporating water to achieve the temperature reduction. This leads to significant energy savings, especially for cooling make-up air, hot air from the outside that needs to be cooled before entering a building air conditioning system. However, the need for water with sufficient purity is unlikely to be sustainable if this is used on a mass scale.

Displacement air conditioning has been used for several decades for buildings accommodating a large number of people, relying on cool dehumidified air being denser than the ambient air. The huge mosques in Saudi Arabia, for example, provide a cool environment for worshippers by maintaining a layer of cool air which is only two or three metres deep. The air conditioning even extends into sheltered open air spaces.

2. Localized air conditioning

Spot cooling people, rather than cooling an entire space within a building offers a feasible alternative to room air conditioning.

Frequent visits to South Asia in summer months motivated the author to seek such a solution. One particularly hot night with power interruptions led to the realisation that it is only necessary to cool the face and neck of a person to achieve reasonable comfort. The rest of the building space does not have to be cooled.

Subsequent technical and commercial development has led to a small portable air conditioner using compressor refrigeration that can provide personal comfort for up to three people. The power required is only 180 – 300 Watts, 75%-85% less than a conventional room air conditioner.

Conventional room air conditioners are designed such that conditioned air enters the room at sufficiently high speed to mix the room air with the result that a single unit achieves relatively uniform conditions throughout the room. A localized air conditioner, on the other hand, has to create a localized micro-climate so air mixing has to be limited. A different approach to the design is needed.

There are two operating modes:

Mode 1) The air conditioner produces a jet of cool air with negligible initial vorticity and with an initial velocity of 2.5 – 8 m/s, resulting in an effective cooling range of 1.5 – 3 m depending on air velocity and temperature. The air jet is aimed at the faces and necks or upper bodies of the users who must be located relatively close to each other, for example sitting on a couch side by side (fig. 2). At the furthest effective distance, the air velocity has been reduced to about 0.5 m/s due to mixing though, even at this distance, the air velocity still produces 2° of apparent cooling in addition to the dry bulb temperature reduction. At higher temperatures, 38 – 45 °C, the effective cooling distance is reduced, and is usually suitable only for one person.

Figure 2. Localized microclimate for up to three people

Mode 2) The air-conditioner supplies conditioned air into a specially designed self-erecting bed tent that also provides insect protection (fig. 3). The upper part of the enclosure consists of relatively pervious fabric such as fine mosquito netting. The lower part of the enclosure consists of relatively impervious fabric. Different designs can be adapted from commercial mosquito nets widely available in tropical countries. The apparent temperature inside the lower section of the tent for a sleeping couple can be as much as 13 °C below the ambient bedroom temperature, providing sufficient comfort for indoor temperatures up to 42 °C (Nicol, 2004).

Experiments with several designs have demonstrated that these two operating modes provide comfortable working conditions and high-quality sleep for people adapted to the local climatic conditions, even for many people who are adapted to cooler weather. It is important to note that some people who spend much of their day in fully air conditioned buildings, both for work and sleeping, lose part of their adaptation in hot weather (Nicol, 2004) and may report less comfort with localised air conditioning.

Several other similar solutions have been proposed.

A conceptually similar design has been proposed by Evening Breeze in The Netherlands (www.evening-breeze.com) in which a low-power split system air conditioner provides cooling air that flows through a pervious canopy over a bed. This design has been specifically tailored for applications in tropical island eco-resorts and continental Europe.

Another design which is conceptually similar to mode 1 above was proposed by Task-Air, a company manufacturing office equipment and furniture in Australia (www.taskair.com.au). Individual air outlets at each workstation allow people to adjust the conditioned air supply to satisfy their needs.

A design similar to mode 2 above is being sold by Tupik in India (https://tupik.in/).

Figure 3. Air conditioned bed tent

3. Design challenges

The most significant challenge in designing such an air conditioner is removing the waste heat. Conventional portable air conditioners rely on large diameter flexible tubing to discharge air from the warm side of the air-conditioner through a nearby window. However, this causes a substantial loss in thermal efficiency because much of the cool air produced by the air conditioner re-enters the inlet vents to be used to cool the condenser, is reheated, and exhausted through the pipe connected to the window. Outside air entering the room to make up for the exhaust air discharged through the window creates a substantial inflow of heat and humidity. Humidity in the room steadily increases as the exhaust cannot keep up with the inflow.

Close Comfort air conditioners operate at such low power that the warmth from the condenser can be discharged into the room. The air rises to the ceiling in the same way as warm air from the rear of a kitchen refrigerator. The net heat that needs to be dissipated in the room is the electrical power input – approximately 300 Watts. This is equivalent to heat produced by three or four active people in the room. The change in room temperature is imperceptible – measurements have shown the temperature rise at the ceiling to be less than 0.5°C, less with doors or windows open. In South Asia, the lack of insulation and draft sealing promotes effective absorption of waste heat at the ceiling.

It is challenging to achieve high levels of thermal performance with small refrigeration components. With careful attention to heat exchanger design, it is possible to achieve a coefficient of performance of about 3.3, depending on the environmental conditions. Using a nominal 250 Watts compressor it has been possible to obtain effective cooling power between 650 Watts in dry air and 1200 Watts in moist humid air (test conditions 33°C, 80% relative humidity). Water condensed at the evaporator is sprayed onto the warm condenser heat exchanger to improve the thermal efficiency, and eliminate the need for a drain tank or hose.

The air conditioner is small: 30 cm x 40 cm x 55 cm and weighs 17 kg. Caster wheels provide easy mobility within rooms, and it is easily carried when needed.

Currently, about 0.3 kg of R134A circulates as refrigerant with a global warming potential of 1300. In future 0.08 kg of R290 (propane) will be used with a global warming potential of 1. Even though R290 is flammable, the quantity is small enough to be well within safety limits for hermetically sealed refrigeration machines.

It was necessary to design the heat exchangers from first principles (Wang, Chang, Hsieh, & Lin, 1996; Wang, Chi, & Chang, 2000; Wang, Tao, & Chang, 1999) so as to minimize the temperature difference between the evaporating or condensing refrigerant in the tubes and the air leaving the heat exchanger. One advantage of a localised air conditioner design is that the temperature difference between the condenser and the evaporator side of the refrigeration cycle is typically less than in a conventional air conditioner design where the condenser is in the outside environment. This means it is possible to obtain higher energy efficiency ratios than would otherwise be the case. Careful heat exchanger design, therefore, partially compensates for the effect of size, and allows a higher energy efficiency ratio to be achieved. The relationship between heat exchanger parameters such as size, fin spacing, air velocity and tube diameter is extremely nonlinear and small changes in the dimensions can have a big effect on performance.

Conditioned air passes through an air straightener and open-cell foam to remove turbulence and vorticity created by the circulation fan (vorticity is the angular momentum component of the total momentum of the air flow). The conditioned air outlet is at the top of the air conditioning unit. The curved air deflector changes the direction of the air flow from substantially vertical to substantially horizontal. The angle of the deflector can be adjusted to aim the resulting air jet at the face and neck of a user, typically seated 1 – 2 m away.

The air conditioner is very quiet (46 – 54 dBA) and the noise is similar to a pedestal fan. The noise can be helpful in suppressing perception of night time sounds in typical communities that come in through open windows.

The return air inlet is below the cold air outlet. This arrangement is necessary in order for the air-conditioner to be connected to the bed tent.

The technology has being commercialised by a small start-up company Close Comfort Pty Ltd, based in Western Australia (www.closecomfort.com).

3. Conclusion

With modest further improvements in power consumption, this technology could provide air conditioned comfort for almost everyone living in hot and humid climates without requiring large increases in electric energy production. It runs conveniently from solar energy (during the day) or a battery backup power supply when grid power is not available. Thermal battery technology based on phase change materials could almost eliminate the requirement for night-time energy supplies (Davis, 2015). However, an appropriate thermal battery is likely to be too heavy to be portable.

Based on current (subsidized) electricity costs in Pakistan, the five year cost of a localised air conditioner running for 10 hours every evening less than half of the cost of a 1800 W (electrical) split system air-conditioner required for a typical bedroom in Lahore (5 year discounted cash flow). A split system air-conditioner stops operating during power interruptions. The localised air conditioner runs continuously because it can operate with power from a typical domestic uninterruptible power supply with a battery backup (UPS). Electricity savings relative to a conventional air conditioner can repay the purchase cost within a few months, depending on how and where it is used.

This technology has the potential to boost human productivity in many parts of the world by enabling people to have a sound night's sleep and work comfortably during the day, without having to expand electricity generating capacity. It is possible to meet energy and greenhouse emission reduction targets without replacing existing buildings.

This technology removes many of the constraints on architecture currently being considered for future buildings. Older style buildings with superior passive performance are equally suitable for localized air conditioning. Traditional open buildings made from light weight bamboo in, for example, South East Asia can be air conditioned this way. Low cost buildings made from locally available materials can be provided with energy efficient air conditioning using this technology.

The commercial prospects for this technology are attractive with appropriate marketing. However, it is necessary to understand the social and economic environment where the technology is to be applied to appreciate the opportunities. With appropriate investment, it will be possible to deploy this technology on a mass scale at a cost affordable to almost everyone within 20 years, eliminating the presently predicted problems associated with room air conditioning technology.

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