Vol. 14 No. 7 February 2019 ₹ 100

Cooling India

India's foremost Monthly dedicated to the growth of HVACR Industry

Cooling without Heating the Earth

A system that utilises less energy for cooling and does not use refrigerants? Yes, you read it right. Here's a case study of an office building in Nashik.

Cooling buildings is a requirement in warm and hot climates, for most part of the year. Globally, cooling consumes 3,900 TWh (almost three times the annual energy consumption of India) and is likely to consume 7,500 TWh by 2050 if we continue at present rate of consumption, according to 'A Cool World' Report published by the University of Birmingham and the Institute for Global Innovation in 2018.

The report points out that the CO_2 emissions from the cooling sector amounts to approximately 4 Gigatonnes of CO_2 annually, amounting to 11.8 per cent of the world's direct CO_2 emissions. Almost 80 per cent of these emissions are due to the indirect emissions of electricity generation to drive the cooling appliances. According to the Draft National Cooling Action Plan (NCAP) released by the Ministry of Environment, Forests and Climate Change (MOEFCC), 60 per cent of India's primary energy supply (TPES) for cooling is accounted for by space cooling in 2017-18. Air conditioning demand by commercial buildings is set to increase from 30 million TR in 2017-18 to 140 million TR in 2038.

The Intergovernmental Panel on Climate Change's (IPCC) Special Report on Global Warming of 1.5-degree C approved by governments in Incheon, South Korea, in October 2018, proposed 'rapid, far-reaching and unprecedented changes in all aspects of society'. The Kigali Amendment to the Montreal Protocol, of which India has been a signatory since 1992, focuses on the greenhouse gas emissions related to Hydrofluorcarbons (HFCs), and the need to integrate energy efficiency to refrigeration transitions.

Do we have an alternative low or zero energy system of cooling our buildings? A system that utilises less energy for cooling and does not use refrigerants?

Rationale for a Natural Cooling System – ThermOdrain (TOD)

The ThermOdrain (TOD) is one such solution that uses water - cooled by night sky to drain the radiant heat within a building. The heat from the structure is absorbed by the water and dumped into the atmosphere by means of a radiator exposed to air. The method aims at reducing sensible heat by removing structural cooling load.

Indoor thermal comfort is achieved if a body can effortlessly remove its metabolic heat from itself. Air conditioning uses chilled air in sufficient quantity to remove the heat and moisture gains from the space and maintain its temperature and humidity to specified values. It also provides treated outside air to maintain indoor air quality through ventilation. However, the assumption is that all solar gains, both direct and transmitted, are sensible loads to be absorbed by air and carried away before they reach the occupants.

This assumption is true in the temperate climate. The houses are light-weight and insulated. They are designed to reduce the heating load during the cold winters by keeping the heat in. Summers are mild. So, the cooling loads are low.

In India, we have hot summers and buildings are un-insulated. They absorb the solar heat and emit it inside. The interior surfaces get heated up and radiate heat. The challenge is to keep the heat out. Instead buildings allow heat to enter through large window openings (or even worse, curtain glass façade) within and then use an energy hungry technology - air conditioning - to pump it out. Sufficient evidence has been gathered till date to show that un-insulated buildings in India absorb solar radiation during the day and release it in the night.

The disadvantage in using air for cooling is that it has very low capacity for absorbing heat. One litre of air weighs one gram and can absorb only one Joule of heat per Kelvin. So, to remove 150 watts (heat generated by one person) would require 540,000 litres/hour of air per person. This figure will increase due to low coefficient of convective transfer for air. While dry air does not need much energy to cool, the moisture in it condenses while chilling and releases its latent heat. Pumping this heat out through refrigeration requires tons of energy.

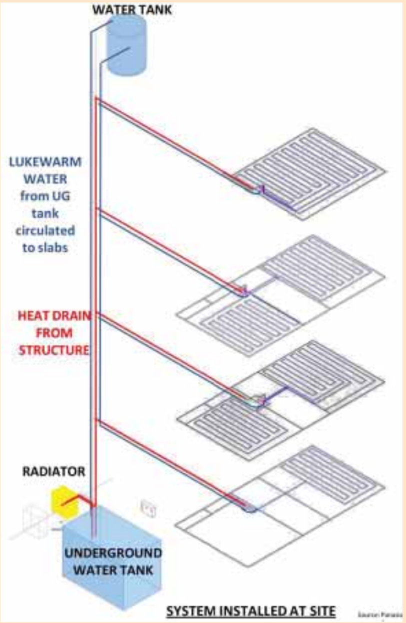
Case Study of Green Space Realtors' Office Building in Nashik:

The case study office building – of Green Space Realtors – is located in the city of Nashik in Maharashtra. Nashik is located at an elevation of 700-metre above mean sea level, has a maximum Dry Bulb Temperature (DBT) of 37-degree C in April/May, while minimum temperatures can reach 10-degree C in January/February. Diurnal range of temperature is about 15-degree C. Average annual rainfall is about 705 mm. Relative humidity fluctuates significantly in a single day. It.

The building is a ground + 2 storeyed building with flat roof admeasuring 258.5 sq.m. carpet area. It is oriented north-south. Entrance is from the North while the South wall is common to adjacent plot building. Overall Wall Window Ratio (WWR) is 30 per cent. Windows are well shaded and have an equivalent SHGC of 0.66. Passive design strategies used in the building include appropriate orientation (South side is a common wall with neighbouring building), use of double wall in the building envelope made of fly ash bricks and brick cladding with air gap, use of turbo ventilators to facilitate stack ventilation and use of high albedo reflective paint with SRI>0.5 to reduce heat gain from roof.

ThermOdrain system at Green Space Realtors' office, Nashik:

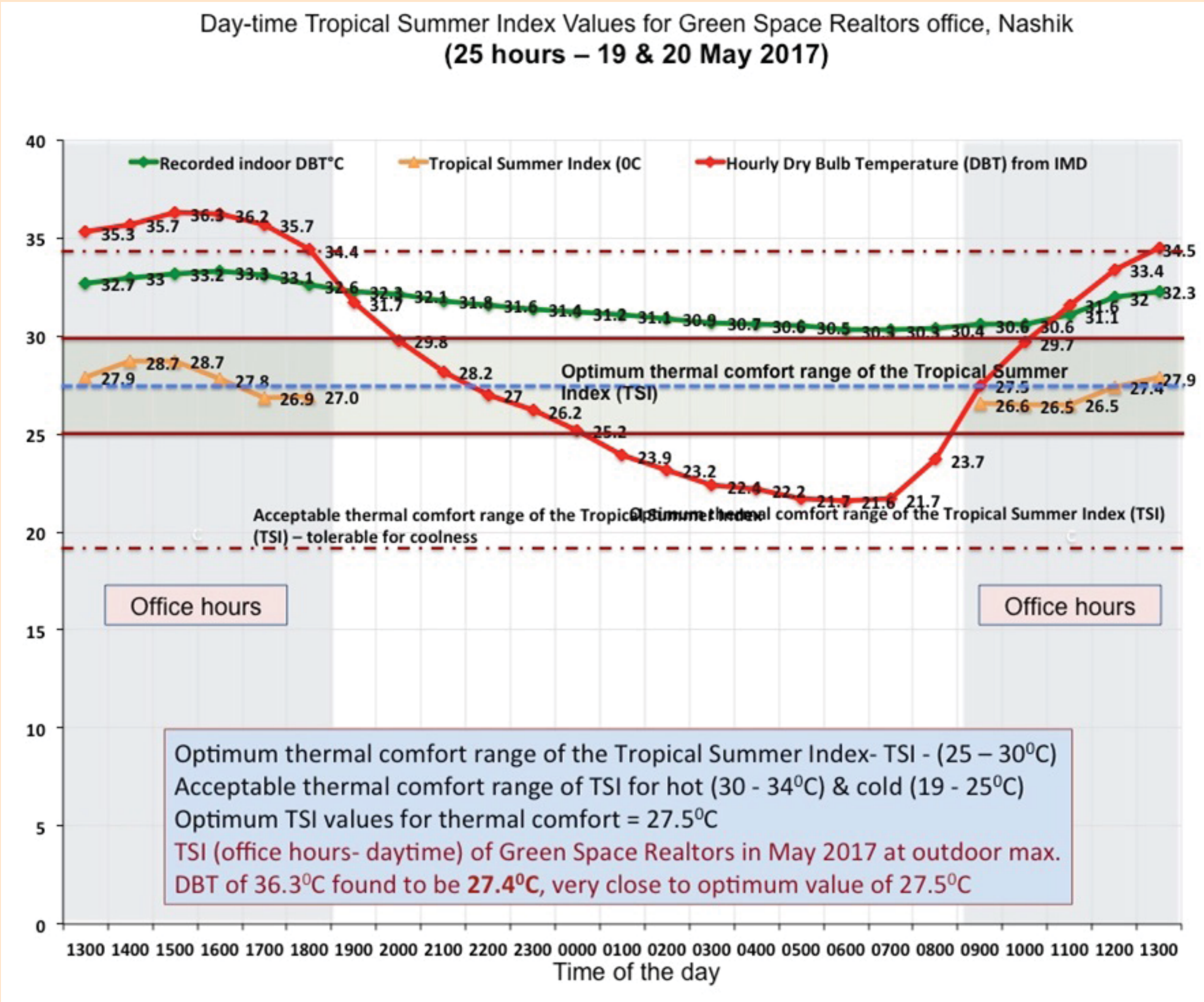
The TOD system installed at the office building in Nashik comprises of 21 mm diameter plastic pipes laid out in a grid on the plinth of all floors. The system is



Schematic diagram of the TOD system for the Office Building in Nashik

Laying out the coil of pipes above RCC slab with screed below tiling at the time of construction of terrace

Completed terrace with water pipes below tiling and high albedo paint above



designed to remove 242 Btu/ sq. ft. / hour (763 W/m2) of heat from the plinth mass of the structure. The schematic layout of the system is shown in Figure 1. Figure 2a and b show the TOD system on terrace slab - during construction and post construction - the finished terrace slab.

The water picks up the roof heat (water absorbs 4,100 joules per litre per Deg. C) and passes through a radiator that rejects most of it. Lukewarm water is stored in the tank and recycled through the radiator at night, when the cool night air absorbs the residual heat. The cycle starts again the next morning. Energy for the pump and the fan is supplied by solar PV system.

Assessment of ThermOdrain system

The ThermODrain system was validated through empirical assessment by recording hourly surface temperature of top and bottom of the terrace slab - with and without high albedo paint. Measurements were made in peak summer (May 2017) using calibrated data logger and thermocouple sensors; hourly indoor air temperature/dry bulb temperature (DBT) and relative humidity (RH) were measured using Ebro temperature and humidity logger; hourly globe temperature was manually recorded using JRN 76 mm black globe thermometer. Monthly electricity bills were obtained from the office to determine Energy Performance Index (EPI) and compared with prevailing benchmarks provided by the Bureau of Energy Efficiency.

Reference Thermal Comfort Standards for India

The National Building Code (NBC) 2016 India refers to three thermal comfort indices that find applications for Indian climate viz:

- Effective temperature (ET)
- Tropical summer index (TSI), and
- Adaptive thermal comfort.

Since effective temperature or ET “appears to have an inherent error if used as an index of physiological strain, the error increasing with the severity of the environmental conditions” as per NBC, it was not considered. For IMAC standards, running mean outdoor temperature for 30 days is required. Hence Tropical Summer Index or TSI was used as a benchmark. Operative temperature was calculated. TSI is defined as the temperature of calm air at 50 per cent relative humidity that imparts the same thermal sensations as the given environment. Mathematically, TSI (°C) is expressed as:

$$TSI = 0.745tg + 0.308tw - 2.06\sqrt{(v+0.841)}$$

Where tw = wet bulb temperature, in degree C; tg = globe temperature, in degree C; and V = air speed, in m/s.

The thermal comfort of a person lies between TSI values of 25-degree C and 30-degree C with optimum condition at 27.5-degree C. As per the index, the warmth of the environment was found tolerable between 30-degree C and 34-degree C (TSI), and too hot above this limit. On the lower side, the coolness of the environment was found tolerable between 19-degree C and 25-degree C (TSI) and below 19-degree C (TSI), it was found too cold.

Thermal Performance of TOD system

Diurnal range of temperature: Outdoor diurnal range of Dry Bulb Temperature (DBT) was 14.7-degree C as compared to indoor DBT range of 3-degree C. Outdoor diurnal range of Relative Humidity (RH) was 71 per cent in contrast to indoor RH range of 27.6 per cent.

Tropical Summer Index: Indoor operative temperature of Green Space Realtors office building in May 2017 at outdoor maximum DBT of 36.3-degree C was found to be 27.4-degree C, which is within the range of acceptable TSI values of 25-degree C and 30-degree C and close to optimum value of 27.5-degree C (Figure 3).

Energy Performance Index (EPI): The EPI, an outcome-based metric for building energy performance, was calculated from monthly electricity bills from June 2016 to May 2017. The EPI for the office building in Nashik was calculated to be 26.5 kwh/m2/year. This falls within the BEE's voluntary 5-Star benchmark for energy efficient buildings (less than 50 per cent air-conditioned) for composite climate of <40 kwh/m2/year, and is way below the national benchmark of 86 kwh/m2/year for commercial buildings in this climate zone.

Conclusions and cost-benefit analysis

The study shows that TOD system provides thermal comfort indoors in peak summer without use of mechanical air conditioning system. The system prevents the solar heat re-radiation from roof and floors by absorbing it before it adds to the sensible heat load of the building and cause thermal discomfort to the occupants.

In terms of capital cost, the structural cooling system is 50 per cent less costly than a conventional HVAC system and the recurring energy cost is a mere 8.7 per cent of a conventional system. The total life cycle costing (capital and running cost) of the TOD system for a period of 10 years amounts to Rs. 6/ sq. ft./ year (US $ 1 per sq. m) as compared to Rs. 30/sq. ft./year for a conventional HVAC system.

The system is passive except for 3 elements – Pump for the pipes grid, Fan for Radiator and Pump for Overhead Tank. The total energy consumption of these amount to 3,000 kwh/year as compared to 34,560 kwh/year required for 12 TR of conventional HVAC system (at 1.2 kw/tonne of refrigeration and set temperature of 24-degree C) required for the building. The difference in energy consumption is more than 10 times. The active components of the system are supplied energy primarily from solar PV panels.

A scientific paper on the above article was presented and published at the 34th International Passive and Low Energy Architecture, Hong Kong University, in Hong Kong on 10 – 12 December 2018 and was adjudged as the 'Best Paper Award'.

Acknowledgment

Author wishes to thank Kiran Chavan, Owner of Greenspace Realtors, Nashik; Architect Sanjay Patil; and structural cooling expert Surendra Shah. She acknowledges the assistance of Dr. Ashok Joshi in validating the empirical set up for the research. ■

Dr. Roshni Udyavar Yehuda
Advisor, Science & Technology Park, Pune; Principal Investigator for Dept. of Science and Technology, Govt. of India; and Head, Operations, MP Ensystems Advisory Ltd.