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A study on the use of phase change materials (PCMs) in combination with a natural cold source for space cooling in telecommunications base stations (TBSs) in China

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HIGHLIGHTS

- A technology that combines phase change materials and cold outdoor air is proposed.
- The technology is for space cooling of telecommunications base stations.
- A prototype unit was built and then tested in an enthalpy difference laboratory.
- An experimentally-validated model was used to simulate the unit's performance.
- The simulated average annual adjusted energy efficiency ratio of the unit was 14 W/W.

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ABSTRACT

A technology that combines phase change materials (PCMs) with a natural cold source is proposed to reduce the space cooling energy of telecommunications base stations (TBSs). First, a mathematical model was developed to assess this technology. Then, a full-scale prototype, named latent heat storage unit (LHSU), was designed, built, and tested in an enthalpy difference laboratory. The energy efficiency ratio (EER) and the adjusted energy efficiency ratio (AEER) were used as the criteria to evaluate the performance of this unit and to compare it with conventional air conditioners. LHSU performance simulations were carried out based on the unit's operation in TBSs located in five Chinese cities with different climates. The simulated average annual AEER was 14.04 W/W, which is considerably higher than the limiting value of 3.2 W/W for air conditioners with a cooling capacity of less than 4500 W. The estimated average energy savings potential of the LHSU was 50%. Based on these results, it was concluded that LHSUs could be used in TBSs to reduce a significant amount of their energy consumed in space cooling.

1. Introduction

The Chinese telecommunications industry is one of the fastest growing markets as well as one of the most competitive ones in the world [1]. A telecommunications base station (TBS) is a transmission and reception station in a fixed location, consisting of electronic, heat generating equipment, used to handle telecommunications traffic between mobile phones and network subsystems. The energy consumption by air conditioning systems in TBSs continues to grow as the number of these stations increases [2]. For example, by the end of 2011, there were more than 2.4 million TBSs in China [3], when the country had an estimated 974 million connections, up 16 percent from the previous year, and which were predicted to surpass 1 billion by the middle of 2012 [4]. As a result of the higher power and thermal density of TBSs, air conditioners work 24 h per day all year round. Currently, the annual electric consumption of the entire Chinese telecommunications network is approximately 20 billion kWh, one third of which is used by TBSs [5], of which the energy consumed by air conditioners accounts for 30–50% [6]. This large energy consumption demonstrates the significant potential for energy savings and makes TBSs a primary target for energy conservation measures in China. In recent years, the proposed energy savings technologies for space cooling in TBSs have consisted only of those that use renewable energy [7]. However, renewable energy distribution is difficult to control and there exists a mismatch between supply and demand. As a result, thermal energy storage

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Nomenclature

A	area (m^2)
c	specific heat (kJ/kg/°C)
d	diameter (mm)
G	volumetric flow rate (m^3/h)
h	specific enthalpy (kJ/kg)
$\triangle h_m$	latent heat of fusion (kJ/kg)
I	electricity consumption (kWh)
l	length (mm)
Nu	Nusselt number
p	pressure (Pa)
P	power (W)
Pr	Prandtl number
Q	heat transfer rate (W)
r	radius (mm)
Re	Reynolds number
T	temperature (°C)
$\triangle T$	temperature difference (°C)
U	overall heat transfer coefficient (W/m^2/°C)
v	velocity (m/s)
V	volume (m^3)

Abbreviations

AC	air cooler
AEER	adjusted energy efficiency ratio (W/W)
EDL	enthalpy difference laboratory
EER	energy efficiency ratio (W/W)
ESM	energy storage module
HFM	heat flux meter
LHSU	latent heat storage unit
LMTD	log mean temperature difference (°C)
PCMs	phase change materials
TBS	telecommunications base station

Greek symbols

α	convective heat transfer coefficient (W/m^2/°C)
γ	melting or solidification constant
ε	relative error
λ	heat conductivity (W/m/°C)
ρ	density (kg/m^3)
τ	time (h)
φ	relative humidity (%)

Subscripts

a	air
ac	air cooler
aw	between air and water
bc	boundary condition
cl	cooling load
cp	copper pipe
ec	energy charging mode
ed	energy discharging mode
ext	exterior space
f	fan
fa	fresh air mode
int	interior space
l	liquid
m	phase change material
n	nozzle
p	pump
s	solid
sat	saturated
w	water
wm	between water and PCM

Superscripts

ed	energy discharging mode
in	inlet
n	Prandtl number exponent in Dittus-Boelter equation (0.4 for heat gain and 0.3 for heat loss)
out	outlet

technologies have drawn significant attention as these can be used not only to assist in solving this mismatch but to save energy [8].

Latent heat storage technologies that use phase change materials (PCMs) allow for the temporary storage of low temperature thermal energy. For example, Turnpenny et al. [9,10] designed a ventilation nighttime cooling system that used a combination of PCMs and heat pipes as an alternative to conventional air conditioning. The system offered substantial benefits in terms of reducing or eliminating the need for compressor-driven air conditioning in residential buildings [11]. Takeda et al. [12] designed a ventilation system containing PCMs for residential buildings. They concluded that the maximum benefit of such system was realized by the reduction of the ventilation load by as much as 62.8% during the summer time when operated in a humid subtropical climate. Parameshwaran et al. [13] concluded that a variable air volume (VAV) chilled water-based air conditioning system combined with a thermal energy storage module could achieve an energy savings ratio of about 47% if demand controlled ventilation, combined with an economizer cycle, were used in a residential building. A passive space cooling system that incorporated PCMs and two-phase closed thermosyphon heat exchangers was installed in telecom shelters in desert and tropical climatic regions in India. It was reported that these could potentially reduce the carbon footprints of the shelters [14]. Baby and Balaji [15] and Mahmoud et al. [16] studied the performance of passive finned heat sinks filled with PCMs in portable electronic devices. An enhancement factor of 18 was obtained in the operation time for a pin fin heat sink when compared to a heat sink without fins for a setpoint temperature of 45 °C. In summary, latent heat storage technologies represent an attractive approach for generating substantially less expensive space cooling in buildings. These technologies, however, have focused mainly on low thermal density buildings [17,18]. Unlike residential buildings, TBSs are characterized by their high power and thermal densities and non-stop operating schedules [2]. Also, unlike residential buildings, there is a significant lack of data related to the application of latent heat storage technology in TBSs.

This paper proposes a technology that combines the use of PCMs with a natural cold source to generate substantially less expensive cool air to reduce the indoor air temperature in TBSs. To evaluate this technology, a mathematical model was developed to identify first order effect parameters, such as heat transfer rates, limiting temperatures on the heat transfer fluids, dimensions of the components and materials. With this information, a full-scale latent heat storage unit was designed, built, and tested in an enthalpy difference laboratory (EDL). The results were compared against data from conventional air conditioners. The energy efficiency ratio (EER) and the adjusted energy efficiency ratio (AEER) were used to evaluate the viability of the proposed technology.