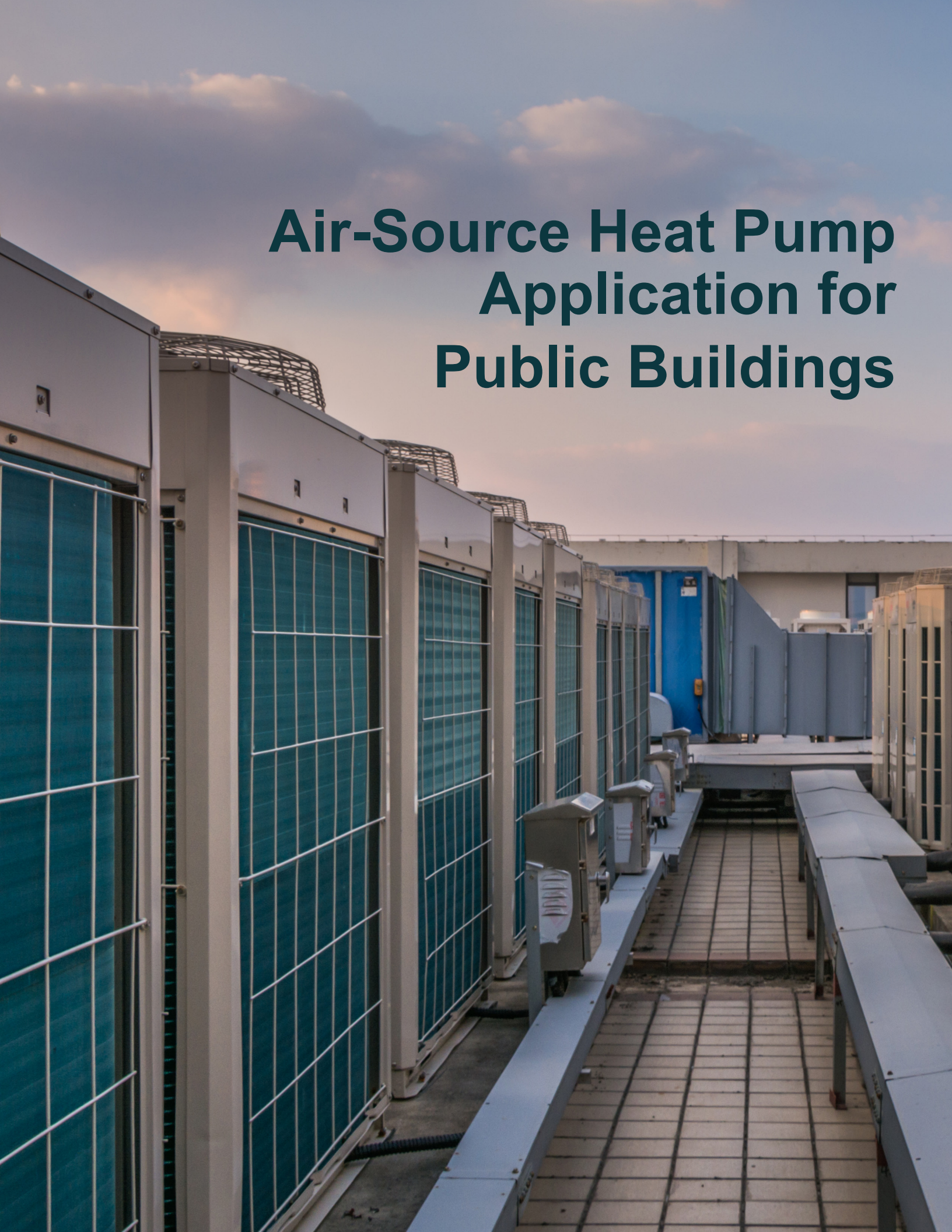


Air-Source Heat Pump Application for Public Buildings

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Authors

Dr. Alexander Zhivov, U.S. Army Engineer Research & Development Center

Dr. Michael P. Case, U.S. Army Engineer Research & Development Center

Mr. Edward Louie, Pacific Northwest National Laboratory

Contributors

Dr. Samuel Thornton, PE, Arctic Heat Pumps

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Preface

Air-source heat pump (ASHP) technology has advanced greatly over the past several decades. Many currently available models of air-to-water heat pumps can produce water temperatures sufficiently high (160–176°F [71–80°C]) to make them suitable to replace or displace fossil-fuel-based hot water boilers. Many models of both air-to-air and air-to-water heat pumps can produce 100% of their rated heat output at ambient temperatures as low as 5°F (–15°C) at a respectable coefficient of performance (COP) of 1.75 or better.

The advancements in heat pumps for cold climates should not overshadow the advancements in air conditioners, which are essentially heat pumps, for hot climates. Options are available to integrate and pair air-source air conditioners and chillers with phase-change thermal energy storage (TES), such as ice storage, to improve cooling capacity maintenance and COPs even during hours of extreme heat.

Air-to-water heat pumps can be paired with cogeneration within a large building or in a district heating system to provide heat and electrical resilience without a need for dedicated fossil fuel boilers or electric resistance heating.

This study and analysis used the criteria of energy use/cost and CO_2 emissions to determine the circumstances and conditions, in 18 different climate zones, under which an ASHP that provides cooling needs and 100% or less of heating needs would represent a favorable replacement alternative to in-kind replacement of existing air-handling units (AHUs) that provide direct expansion (DX) cooling and boiler-generated heating. The scope of this analysis was thus limited:

- It did not compare ASHP with district heating and cooling systems.
- It was based on (typical U.S.) power grids with a range of fossil fuel usage for power generation.
- It did not assume the use of thermal and power storage in the energy supply system architecture.
- It did not include domestic hot water.
- It did not apply to water-source heat pumps.

Analyses incorporating the above-listed factors may yield different outcomes. This analysis was conducted by the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL), with participation from Pacific Northwest National Laboratory (PNNL).

Chapter 2, “Air-Source Heat Pumps (ASHPs)” discusses general ASHP types, their applications, and specific case studies.

Chapter 3, “Methodology” delineates the parameters, system architectures, and demand profiles derived for the simulations. The demand profiles are based on two types of buildings included in the brigade combat team (BCT) building complexes: barracks and office buildings. The demand profiles for these buildings were matched with representative U.S. public/military locations in the 18 U.S. Department of Energy (USDOE) climate zones, defined in Section 3.2, which also includes the source for typical meteorological year, edition 3 (TMY3), weather data that form the basis for the temperatures, solar radiation, wind speed, humidity, and precipitation ranges used in this analysis. Section 3.3 outlines the system architectures of the simulated alternative energy systems. These architectures are divided into cold/moderate climate zones and hot climate zones (Section 3.2) but share the same baseline system architectures, which form the basis for the criteria used to compare the results. The baseline system architecture consists of all the heat demand being met with a boiler, cooling demand being met with an electric chiller, and electricity demand being met with electricity imported from the public grid, including for the consumption of the electric chiller. The hot climate system ASHP architecture consists in its entirety of heat pumps. While the cold/moderate

climate system architecture is like the hot climate architecture, it differs with the addition of electric resistance heating to complement the heating plant (HP) in meeting heating needs below a certain outdoor air temperature.

Chapter 4, “Input Data and Boundary Conditions,” presents input data and boundary conditions and summarizes energy prices, heating values, emissions rates for the imported electricity, maintenance costs of equipment, efficiencies of the equipment used, and the capital expenses (CAPEX) for the equipment. All of these were determined from the research and industry experience of the involved contributors referenced in each category. The energy prices are divided into three categories for both the import of electricity and purchase of natural gas, except for Fairbanks, which was assigned a fourth category, “extra-high (Alaska) prices,” denoted to accommodate the higher energy prices in Fairbanks given the less integrated gas infrastructure and higher electricity transmission costs. The emission rates for the site electricity were similarly divided into three categories that denote the potential emissions levels associated with the site electricity (in MWh).

Chapter 5, “Results,” presents the results of computer modeling showing that, for ASHPs in general, total site energy usage is reduced compared to the baseline conventional boiler/chiller alternative. Energy costs are reduced except in the coldest climate zones. Emissions depend very much on the energy mix on the local electrical grid. Finally, simple payback is generally positive for most climate zones (except for the coldest) but may or may not be shorter than the expected equipment life, especially in coastal areas exposed to salt air.

Chapter 6, “Discussion and Conclusions,” outlines the findings from the simulated climate zones and makes recommendations for alternative energy technology and equipment setup solutions.

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Abbreviations and Acronyms

AC	alternating current
AHU	air-handling unit
ASHP	air-source heat pump
BCT	brigade combat team
BDE HQ	brigade headquarters
BLDC	brushless direct current
CAPEX	capital expenses
CCASHP	cold-climate air-source heat pump
CHP	combined heat and power
COP	coefficient of performance
CZ	climate zone
DC	direct current
DHP	ductless heat pump
DHW	domestic hot water
DSHP	ducted split heat pump
DX	direct expansion
EH	extra-high
GWP	global warming potential
HFCs	hydrofluorocarbons
HFOs	hydrofluoroolefins
HP	heating plant
HVAC	heating, ventilating, and air-conditioning
IDU	indoor unit
LPG	liquefied petroleum gas
NA	not applicable
NG	natural gas
PTHP	packaged terminal heat pump
PWM	pulse-width modulation
RTU	rooftop unit
SMPL	system master planner
SPB	simple payback
TES	thermal energy storage
TMY3	typical meteorological year, edition 3
TOU	time-of-use
USDOE	U.S. Department of Energy
USEIA	U.S. Energy Information Administration

USEPA U.S. Environmental Protection Agency
VRFHP variable-refrigerant-flow heat pump

CHAPTER 1.
INTRODUCTION

This book presents the analysis of the possibilities of using air-source heat pumps (ASHPs) in renovation projects that will enable the U.S. Army to transition to more environmentally friendly alternatives to currently used heating and cooling systems.

ASHP technology has advanced greatly over the past several decades. Many currently available models of air-to-water heat pumps can produce water temperatures sufficiently high (160—176°F [71—80°C]) to make them suitable to replace or displace fossil-fuel-based hot water boilers. Many models of both air-to-air and air-to-water heat pumps can produce 100% of their rated heat output at ambient temperatures as low as 5°F (–15°C) at a respectable coefficient of performance (COP) of 1.75 or better. One cold-climate ASHP air-to-water model is specified to operate at temperatures as low as –22°F (–30°C), with a COP of 1.46, an output water temperature of 113°F (45°C), and a drop in heating output of about 10%.

Technologies in ASHPs such as inverter-driven variable-speed fans and compressors contribute significantly to their improved cold-climate performance and can also improve cooling capacity maintenance and COPs even during hours of extreme heat. The integration and pairing of these technologies with phase-chase thermal energy storage (TES), such as ice storage, can further extend capacity and maintain COP even in more extreme temperatures. Ice-based TES systems freeze water into ice overnight during the coolest hours of the day—typically when the facility's electricity use is low, to avoid raising demand charges——and (in regions with time-of-use [TOU] rates) when electricity cost is lowest. During the peak cooling hours, the system switches to rejecting some or all of the building's heat into the TES instead of into the hot ambient environment, melting the ice (in the case of ice storage) and improving the COP and cooling capacity maintenance. The system can improve resiliency at the building or campus/district level by pairing cogeneration with air-to-water heat pumps so the cogeneration can produce electricity to power the heat pumps during a grid power outage and supplementary heat during periods of extreme cold.

The analysis described in this book explores how many hours in the year, modern ASHPs can adequately meet the heating and cooling loads of a modeled set of buildings that represent a U.S. Army installation. The analysis used computer modeling to consider a wide range of climate zones, from Fairbanks, Alaska (CZ 8), to Guam (CZ 0). For heating applications, during hours when an ASHP cannot meet a building's heating load, auxiliary heat from electric resistance or fossil fuel sources will supplement or take over the heating load. The average price of electricity, natural gas, heating fuel oil, and propane in the different climate zones will be used to assess the cost effectiveness and cost savings of switching to an ASHP. The National Renewable Energy Lab's Cambium data were used to calculate the carbon emissions associated with electricity usage at each hour of the year in each of the modeled locations. This carbon footprint was compared with the carbon footprint of the common heating and cooling systems currently used in each modeled climate zone location to determine carbon savings.