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The life cycle assessment of a solar-assisted absorption chilling system in Bangkok, Thailand

Jacob Bukoski[a,b], Shabbir H. Gheewala[a,c,d,*], Ashley Mui[a,b], Mathew Smead[a,b], Surapong Chirarattananon[a,c]

[a] Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangkok, Thailand
[b] Institute for the Environment, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA
[c] Center for Energy Technology and Environment Office, Ministry of Education, Thailand
[d] Department of Environmental Science and Engineering, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

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ABSTRACT

Life cycle assessment (LCA) methodology following ISO 14044:2006 standard is utilized to analyze the environmental impacts of implementing a solar/electric hybrid cooling system in a stadium of 15,000 seating capacity. Four impact categories are investigated: 100 year global warming potential (GWP), acidification potential, eutrophication potential, and abiotic resource depletion (ARD) potential. The life cycle emissions of the solar-assisted absorption chiller (AC) system are compared to that of a conventional electricity-consuming vapor compression (VC) chilling system. The use-phase electricity consumption of the VC and the life time cooling production of the solar-assisted AC are simulated. The results yield reduced AC system net life cycle impacts for GWP, acidification, eutrophication and ARD potentials by factors of 25.8, 40.1, 33.6, and 37.7%, respectively, when compared with those of the VC system. It is found that use-phase impact savings due to the cooling production of the solar AC outweigh the higher non-use phase (raw material extraction, refining, unit manufacturing, transportation, and disposal) impacts of the solar-assisted AC system, and thus the system is found to be environmentally advantageous. The results are applicable to similar cooling systems and building systems within Southeast Asia.

1. Introduction

Thailand has long been seeking to reduce its dependence on foreign fossil fuel energy sources, improve energy conservation in buildings, and increase the percent of national electricity produced from renewable energy sources [1,2]. The Thai Ministry of Energy recently set goals to meet 25% of its total domestic electricity supply through alternative energy sources and technology by the year 2021 [1]. In Thailand, office buildings are estimated to account for approximately 44% of the total annual electricity consumption in the commercial sector, and an increase in new building construction of approximately 35% was seen in the three year span from 2002 to 2005 [3]. Thus, it can be seen that electricity consumption in buildings is a prime sector for the Ministry of Energy to promote their alternative energy goals through. Of building energy consumption, building cooling loads are estimated to account for approximately 60% of an office building's total energy demand [4]. Additionally, local residents of tropical regions are found to spend approximately 90% of their time in cooled buildings [5], and thermal comfort is found to have significant effects on occupant work performance, mood, and attentiveness [6]. As building cooling based greenhouse gas emissions could increase by 26–70% from 2020 to 2080 due to climate change [7], the reduction of cooling based energy consumption via implementation of alternative cooling system technologies presents one such environmentally-conscious means for Thailand to pursue its energy related domestic goals without curbing economic and societal development.

It is found that for low-energy systems, the operational phase has a reduced influence on the overall net life cycle impact when compared with those of standard systems [8]. When technological efficiencies improve, the operational phase is found to consume less energy and the non-operational phases are consequently found to account for a greater proportion of the total emissions. In order for future improvements on these low-energy systems to be facilitated, proper identification of the most influential life cycle phases–either operational or non-operational–must be performed. Additionally, globalization and outsourcing of production methods have made it common for appliances to be produced in one region of the world, and used in another. The energetic profiles of a site of unit

* Corresponding author at: Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, 126 Pracha-Uthit Rd. Bangmod, Tungkru, Bangkok 10140, Thailand. Tel.: +66 2470 8309x4139; fax: +662 872 9805.
E-mail addresses: shabbir_g@jgsee.kmutt.ac.th, shabbirg@hotmail.com (S.H. Gheewala).

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Table 1
Expected scenarios of use for the stadium facility and administrative offices.

	Office use per week	Stadium use per week	Cooling required per week	Cooling required per annum
Use (hours)	63	10	73	3,796
Average cooling required per hour of use (RFT-hr)	25[a]	800	–	–
Cooling load demand (RFT-hr)	1,575	8,000	9,575	497,900

[a] An average cooling load of 25 RFT-hr is expected for 500 m^2 of administrative office space, as calculated by the local consulting firm.

manufacture and a site of unit operation can be vastly different, with different key fuel energy sources, and energy-associated emissions for each. Rossi and colleagues found that in a study of three different European building systems, the use phase contributed the most to the net life cycle impact in terms of CO_2 emissions, and that the locality-specific energy mix was highly influential on the use phase impacts [9]. Thus, for technology systems that are produced in one country and operated in another, analyses of life cycle emissions that are sensitive to locality-specific characteristics are necessitated for a full understanding of the associated environmental impacts.

Solar-assisted absorption chilling (AC) is one such technology that can significantly reduce fossil fuel based electricity use in buildings in Thailand. Optimization studies of AC system efficiencies are common within the general literature and commonly focus on AC system efficiency, sizing, and technological improvements [10–13]. While these studies undeniably result in forwarding utilization of AC technology, little research has been performed to assess and identify the most influential non-operational phases on net environmental impacts from a locality-sensitive process based life cycle perspective [11]. Life Cycle Assessment (LCA) has been shown to be an integral part of product development, system design, and system selection [14–16]. This paper looks to provide further insight on the most influential life cycle phases of low energy cooling systems using LCA methods for system selection and product development. A LCA of a solar-assisted AC, produced in China and utilized in a stadium of 15,000 seating capacity, in Bangkok, Thailand, was conducted in accordance with ISO 14044:2006 standard. The following study evaluates and reports the life-cycle environmental consequences from the implementation of a solar-assisted single/double effect Absorption Chiller of 159 refrigeration ton (RT) based cooling system in such a stadium.

2. Description of the proposed cooling systems

The rationale and design of the proposed cooling systems are described in the following sections.

2.1. Expected cooling demand and scenario of use of the stadium

The solar-assisted AC evaluated in this study is to be implemented in a multi-purpose, 15,000 seat, five story-high stadium located in Bangkok, Thailand, designed to accommodate a range of sporting events, expositions, and concerts. Scheduled use of the stadium facilities is expected to be highly variable. A reference scenario of use is assumed for the stadium, in which the office spaces are used daily and the stadium itself is used for one scheduled event per week. Cooling of office spaces from 9:00 to 18:00 seven days a week requires a total of 1575 refrigeration tons (RFT) of cooling. The peak cooling demand of the stadium facility itself is calculated to not exceed 1500 RFT at any given time. A corresponding average cooling demand of 800 RFT per hour of use of the stadium is estimated and includes hours of both low demand (custodial work before or after an event) and peak demand (high excitement and maximum occupancy during the event). Cooling for one stadium event is required for 10 h and thus one use of the stadium requires an average of 8000 refrigeration ton hours (RFT-hr) of cooling. The reference scenario of use is subsequently estimated at approximately 9575 RFT-hr per week and is used to evaluate the use-phases of the two proposed cooling systems in the following study. The expected uses of the office spaces and stadium facility are summarized in Table 1.

2.2. Cooling system configurations

The proposed cooling system to meet the cooling load demand is conventional and would consist of three primary and one stand-by vapor compression (VC) chiller of 500 RT that provide immediate cooling by direct consumption of Thai grid-mix electricity. The coefficient of performance (COP) of the 500 RT VC assumed to run at 80% efficiency is evaluated at 5.02 with a primary power of 280.2 kW and 500 RT cooling capacity. Alternatively, the use of a cooling system that is designed around the use of a solar-assisted single/double effect AC of 159 RT cooling capacity was proposed. The COP of the AC is evaluated at 0.80 using the technical modeling results described in Section 3.5. The COPs of the AC system is high due to the fact that it is a single/double effect AC and can capitalize on a wider range of heat input, but corresponds with standards within the academic literature. The AC is designed to be paired with 2000 m^2 of compound parabolic concentrator medium thermal evacuated tube solar collectors (CPC) that will supply the thermal energy input to run the system. Chilled water produced by the AC during hours of sufficient solar thermal heat gain is to be stored in an insulated chilled water storage tank (CWST) of 3500 m^3 over the course of the week and is to be used during weekend stadium events when the cooling load demand is expected to be the largest. No chilled water storage would be included in the conventional system, as the VCs would provide immediate cooling by running during hours of cooling load demand. The AC cooling production is not expected to meet the full weekly cooling load demand due to variation in solar heat gain, and thus the AC is paired with a back-up VC of 500 RT, and a stand-by VC of 500 RT to be utilized when the back-up VC is under repair. The following study compares the life cycle impacts of the proposed AC system with all associated components to those of the VC system. The VC system is denoted as Configuration 1 and the solar-assisted AC system is denoted as Configuration 2.

3. Methodology: life cycle assessment

A process based LCA using locality specific parameters is utilized to assess the environmental impacts of the two proposed cooling systems.

3.1. LCA methodology

A process based LCA with locality specific energetic inputs (e.g., Thai vs. Chinese grid fossil fuel mixes) is appropriate for the quantification and comparison of the life cycle environmental impacts and resource requirements of the two proposed cooling system configurations. A mapping of all processes within each phase of