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Passive Cooling Energy Systems SWOT Analyses for Energy-Use Reductions at Three Spatial Levels

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Abstract

Passive cooling energy systems are significantly important in achieving efficient design and performative built environment. Encouragingly, there are many passive cooling energy systems at three spatial levels of macro, meso and micro. In this research study, these energy systems are identified and are assessed in a SWOT analysis evaluation. Apart from social and economic implications that are broad and effective for most of passive cooling energy systems, this study focuses on the energy systems' implications across five indicators of practice, health, environment, energy and policy, which are significant for disciplines of sustainable energy systems and the built environment. This study aims to evaluate the interdependency of each indicator across three spatial levels and then argue for methods that can be considered for potential implementation of passive cooling energy systems. Furthermore, this study offers a holistic overview of all available passive cooling energy systems and argue based on interplay between five indicators across the three studied spatial levels. This study focuses on warmer climate zones (e.g. hot and dry; hot and humid), where passive cooling is expected to me more effective and obligatory. As a result, this study aims to help energy specialists, policy makers, planners and designers to evaluate how they can utilize passive cooling energy systems based on the key studied indicators. Finally, this paper gives an overview of gaps in policy and practice implementation of such systems in practice and their effectiveness at various spatial levels of the built environment.

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Keywords: Passive Cooling; Energy Systems; SWOT Analysis; Spatial Levels.

1. Introduction

In the fields of energy and the built environment, there are already many studies that explore passive cooling energy systems, mostly individually, at various spatial levels, but none has so far offered a comprehensive SWOT analysis of all passive cooling strategies for the sole purpose of energy-use reductions and suggestions for better environmental and health qualities. This study offers not only SWOT analyses of passive cooling energy systems at three spatial levels of macro, meso and micro, but also provides a cross-evaluative platform for holistic understanding of existing systems for and in the built environment. The overall aim of this research study is to identify, assess and recommend passive cooling

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energy systems for the reduction of active loads and energy use. The outcomes of this study are mainly for the benefit of tropical, hot and arid climate zones, where cooling load is a significant part of energy use. In light of the above brief introduction, this study explores the following two research questions: 1) *How SWOT analysis can help us identify the effectiveness of passive cooling strategies at different spatial levels?* 2) *What are the gaps in policy and practice implementation of passive cooling energy systems at different spatial levels?*

2. Passive Cooling Energy Systems at Three Spatial Levels

In this paper, we first categorise passive cooling energy systems at three spatial levels of macro, meso and micro, including systems from city-scale approaches to building-scale technologies (table 1). This categorisation is then used for the comprehensive SWOT analyses of all systems at each level.

Table 1. Passive Cooling Energy Systems at Three Spatial Levels (Source: Authors)

Macro Level	Meso Level	Micro Level
1. Urban Geometry & Patterns	1. Urban Layout (Configuration)	1. Solar Shading
2. Urban Canyons	2. Density	2. Greening (shading)
3. Urban Cool Islands (UCIs)	3. Orientation (Passive Solar Cooling)	3. Thermal Mass and Materials
4. Green Infrastructure (GI)	4. Compactness	4. Insulation
5. Bioclimatic Planning & Design (BPD)	5. Construction Materials	5. Solar Chimney
	6. Green Infrastructure	6. Air Vents/Natural Ventilation
		7. Wind Towers
		8. Radiative Cooling
		9. Evaporative Cooling
		10. Earth Coupling (Earth Cooling)
		11. Building Envelope

According to this categorization, the below SWOT analyses further assess the systems' implications across five indicators of: 'practice (PR)', 'Health (H)', 'Environment (EN)', 'Energy (EG)', and 'Policy (PO).

A. SWOT Analysis of Passive Cooling Energy Systems at Macro Level

- ***Urban Geometry and Patterns:*** **Strengths -** Increase of wind field and speed (PR/PO); Hierarchy of heights for prevailing winds (PR/PO); Channelization of prevailing wind flow (PO) [1][2]. **Weaknesses -** Penetration through the urban fabric (PO); Streets not aligning accordingly (PR); The blockage effect (PR) [2]. **Opportunities -** Angled geometry (PO/PR); Height-volume ratio (PO/PR); Permeability of urban fabric (PO); Varied air speed for varied temperatures (H); Building axis consideration (PO/PR) [1][2]. **Threats -** Difficulty with air flow distribution in high density (PR/PO); Lack of planned networks (PR/PO); affecting indoor thermal comfort in buildings and safety of pedestrians (H/EN) [3].
- ***Urban Canyons*** **– Strengths:** Channelization and removal of air pollutants (H/EN); Temperature reduction (PO/EG) [4][5][6]. **Weaknesses –** Direct contribution to urban heat island effect (UHIE) (EN/H); Lack of effectiveness in higher density areas (PR/EN); Provision of more solar access in certain cases (PR/EN); increase of pollution concentration (PR/EN) [4][5][6][7][8]. **Opportunities –** Mandatory implementation of air ventilation (PO); Assessments optimisation or maximization of air ventilation through urban fabric (PR/PO) [2]. **Threats –** Potential channelling of air pollution downwind (PR/EN) [4].
- ***Urban Cool Islands (UCIs):*** **Strengths –** Increase of reflective surfaces (PO); Increase of vegetation and natural cooling (PO); Utilisation of trees as urban canopies (PO); Storm water filtration and groundwater recharge (PO/PR); Reduction of greenhouse gas (GHG) emissions (EN/H); Channelization of wind paths (EN/PR); Alleviation of air