Passive Cooling Energy Systems: Holistic SWOT Analyses for
Achieving Urban Sustainability

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Abstract

In urban sustainability, passive cooling energy systems are recognised as primary design factors that highlight efficient and performative buildings. In the literature, there is a gap in addressing these design systems in the form of strategies that holistically suggest sustainable energy systems, cleaner built environments, and urban sustainability. This study fills this gap by conducting a comprehensive SWOT analysis of all major passive cooling energy systems. In doing so, the study highlights key implications from a multi-indicator perspective comprised of five primary indicators, 'energy', 'policy', 'practice', 'health', and 'environment'. These indicators are significant for disciplines of sustainable energy systems and the built environment. Through an in-depth interdependency evaluation of these indicators, this study assesses the passive energy systems across three spatial levels of macro, meso, and micro. Finally, this paper provides a holistic overview of these sustainable energy systems from the policy and practice perspectives across the three spatial levels.

Key words: *Passive Cooling; Urban Sustainability; Ventilation; Energy Systems; SWOT Analysis; Spatial Levels.*

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Introduction

In general, buildings are noted to be major contributors to energy consumption in the 21st century (Chenari et al. 2016). Energy consumption consists of lighting, use of electrical appliances and HVAC systems. According to Hughes, Chaudhry et al. (2011), these can be classified into two primary methodologies; the first is for maintaining internal comfort and second to generate power for running appliances. Either classification leads to increased GHG and CO_2 emissions. Moreover, buildings account for 40-50% of the world's energy consumption (Asif et al, 2007). When all these buildings are clustered together they form communities/neighbourhoods, districts and cities, these cities further account for as 75% of the world's energy consumption (Asif et al, 2007; Lehmann, 2015). For instance, for cooling, HVAC systems consume about 30 - 40% energy in domestic and commercial buildings (Gruber et al, 2008). In addition, in areas of hot climatic conditions and high humidity, ventilation is one of the primary cooling tools for improving thermal comfort (Givoni, 2009). Hence, large energy consumption, shortage in conventional sources of energy and escalating energy prices has prompted the revaluation of air-conditioning, HVACs and general design practices. This has led to the application of passive energy design techniques (energy efficient design) in the built environment (BE) to reduce energy consumption, improve thermal comfort and health, all the while considering the environmental impacts (Geetha and Velraj 2012). This view of passive design in buildings stretches far beyond buildings but also considers the entire urban environment from a neighbourhood scale (Meso level) to city scale (Macro level).

The aim of passive cooling techniques is the utilisation of natural means such as convection, radiation and conduction to balance and improve indoor comfort (Kamal, 2012). However, from the urban perspective, outdoor thermal comfort is just as important; and the utilisation of passive strategies for outdoor spaces

would have a ripple effect on indoor air quality. These principles or strategies include the understanding of climatic conditions, such as solar radiation, temperature, humidity, wind direction and green infrastructure present within the region (Capeluto 2005). This provides a different perspective into how cooling is viewed, i.e. from neighbourhood or city perspective, which is yet to be studied comprehensively. Another perspective is the challenges that each spatial level faces in terms of passive cooling. For instance, cities tend to have higher temperatures than non-urbanised areas, a phenomenon known as urban heat island effect (UHIE), which is known to manifest on a city level but is influenced by micro level activities (Jusuf et al, 2007). On the neighbourhood scale, urban form shapes how solar access and ventilation optimises ventilation strategies and is seen as particularly influential on this scale (Owens 1986; Ko 2013). These are only a few passive cooling design challenges that operate or become more dominant at various spatial levels. Furthermore, though passive cooling is the focus of this paper, its associated effects play a significant role in its analysis. This is followed by the analysis of health impacts from passive design strategies, which has received little attention in research. Apart from the fundamental effects, passive cooling implementation needs to be considered. Design and practice are two important aspects of passive cooling at all levels; but from a neighbourhood or city level, implementation could also be an institutional affair, i.e. in terms of policy and governance. For instance, strategic plans are essential for events such as extreme heat events (EHE), which involves increasing vegetation and green infrastructure (GI) (O'Neill et al., 2009); thus, addressing the issues of UHI by reducing urban air and surface temperature (Bowler, Buyung-Ali, Knight, & Pullin, 2010). Consequently, for this to be addressed substantially, it has to be widespread implementation; i.e. implementation at the city level. Hence, passive strategies should be understood at multiple levels of the built environment, which is identified as a research gap. This study, therefore, responds to this gap by providing a comprehensive analysis of all available passive strategies at three spatial levels of the BE.

In the fields of energy and the built environment, many studies already explore passive cooling energy systems (Hughes, Chaudhry et al. 2011, Kamal 2012, Taleb 2014, Dehghani-sanij, Soltani et al. 2015). However, these studies are mostly conducted either from individual analysis of specific passive design strategies or at a specific spatial level of the BE. More importantly, various passive cooling techniques exist at different levels with their pros and cons. The so far methodological approaches in the field are either technical studies or broad review of specific strategies, such as façade design, retrofit design of buildings, passive techniques, thermal mass, thermal comfort, etc. The largest gap is lack of studies that cover multiple spatial levels (Cheshmehzangi, 2016; Deng and Cheshmehzangi, 2018), which is studied in this research paper. More importantly, this study offers 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. It takes into consideration five key essential indicators of 'practice (PR)', 'Health (H)', 'Environment (EN)', 'Energy (EG)', and 'Policy (PO), which represent the whole spectrum of implications in the current literature. Unlike existing research, this study offers a set of comprehensive SWOT analyses of passive cooling energy systems at three spatial levels of macro, meso and micro. This method is selected as it provides a comprehensive overview of each passive cooling energy system, not only from a positive perspective of strengths and opportunities (S and O), but also negative aspects of weaknesses and threats (W and T) that require further attention in design and practice. The novelty of SWOT analyses here is to provide a cross-evaluative platform for holistic understanding of existing systems in the BE. The main disadvantage is that SWOT analysis cannot be conducted with subjective analysis; hence, to overcome this disadvantage, all key points are cross-checked with multiple references (where needed). This approach provides a set of findings that can then be useful for both design and practice of passive energy systems and strategies.

In summary, the overall aim of this research study is to identify, assess and recommend passive cooling 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 humid, and hot and arid climate zones, where cooling load is the significant part of energy use. The focus of this study is more towards the context of developing countries where energy-use is not necessarily a major problem yet, but with rapid growth, urbanisation and development, this can lead to a major challenge for growth and development. In light of this main aim, this study responds to the following two questions:

(1) How to evaluate the effectiveness of passive cooling systems at multiple levels and through a comprehensive SWOT analysis?

(2) What are the specific policy and practice gaps in the evaluation of passive cooling energy systems as sustainable strategies in achieving urban sustainability?

The first question is explored through the proposed SWOT analyses, while the second question is later explored in detail based on the proposed 'Matrix' (including five mentioned indicators) and further discussions.

Literature Review: The Micro- Meso- Macro- Phenomenon

It has been established that passive cooling functions in such a way as to improve indoor air door quality, thereby optimising thermal comfort through natural purposes (Parsloe, Race et al. 2005; Taleb 2014). On a micro scale this process can be done with either mechanical equipment, such as, fans or blowers termed mechanical ventilation or via natural means that uses no mechanical vices per say termed as natural ventilation (Chenari et al. 2016). The focus of this section is a brief outlook of passive cooling techniques and its proclivities towards cooling. For this to be done, a brief overview will illustrate the available techniques that exist and the causal effects of passive cooling. It also gives a comparison and contrast of various techniques at different spatial levels.

Nowadays buildings are mechanically ventilated predominantly with the use of air-conditioning (AC) to control moisture content, temperature and circulation and purity of air within a space for the sole purpose of optimising human comfort (Chenari et al. 2016) . This invariably increases energy consumption and risks of climate change, all this is in light of the shortage of conventional energy resources and escalating energy costs (Geetha and Velraj 2012). Energy consumption is one of the key impacts of mechanical ventilation, and in general, provides much of the difference between passive cooling systems. These systems are known to mitigate the risk of climate change and reduce CO_2 emissions compared to mechanical ventilated systems (Lomas and Ji, 2008) .

Another mode of cooling exists in the form of a hybrid system or mixed mode system, which combines the systems together. This is predominantly utilised in the situation where passive cooling techniques are not favourable; thus, being compensated by the mechanical systems (Kamal, 2012). These systems, in some cases, raise the effectiveness of passive cooling techniques with mechanically assisted heat and ventilation transfer techniques. This concept falls on the very principle of 'trias energetica' which was developed by Lysen in 1996. Lysen (1996) proposed three basic strategies for the built environment; firstly, prevent the use of energy by reconsidering the energy use (prevention), secondly, use of sustainable technologies (renewable), and finally, deficit energy demand after the application of the one and two should be done as efficiently as possible. Relating to this ideology, passive cooling follows the first step ideology of prevention. However, the motivations for its utilisation vary. For instance, climate change and its impact on the built environment have been one of the key components and motivations for passive cooling strategies like natural ventilation (Dursun and Yavas 2015). However, a socially oriented perspective exists, which is the human comfort. This factor also warrants a shift from fixed conditions to a more controllable condition (Holmes and Hacker, 2004); i.e. the ability of humans to adjust room temperature accordingly instead of being constricted to temperature standards by automated systems.

Sometimes when it is difficult to remove or control the source of indoor pollution, and air filtration is ineffective, the removal of pollutant is most effective with fresh outdoor air. This indicates the dilution of indoor pollutants with outdoor air. Moreover, this method serves the purpose of clean oxygen for human respiration, the dilution of gaseous contaminants to limit long term exposure toxic odours and vapours of chemical origin, controls humidity levels due to lower moisture content of outdoor air and promotes healthier environment due to proper air distribution (Awbi, 2003). Irrespective of these advantages, challenges still exist and perhaps the most interesting or critical challenge of passive cooling is how this can be controlled; i.e. how can the rate of air exchange be controlled whilst simultaneously removing excess heat during the cooling season or even minimising heat loss in the heating season. This is due to the fact that mechanical systems provide constant ventilation rates. This can be quite unpredictable for natural cases due to the unknown flow velocity and friction of wind (Awbi 2006). This is always compounded by the complex and unsteady flow of wind in and around a building, which is highly affected by choices in design. Nonetheless, the direction of wind and its effects have a significant role to play if fully understood (Ahmad 2005; Li 2009; Stavridou and Prinos, 2013). A study by Capeluto (2005) developed a tool that assessed the characteristics of wind and its direction for providing natural ventilation in the BE. His study had a simple conclusion that wind humidity and air temperature are main parameters of determining the human comfort.

Explanations to passive cooling techniques as well as their environmental implications and energy impact are well documented in the literature (Shashua-Bar and Hoffman 2003; Bonta and Snyder 2008; Sadineni, Madala et al. 2011; Geetha and Velraj 2012; Taleb 2014; Dehghani-sanij, Soltani et al. 2015). Table 1 lists these techniques utilized, majorly on a micro level. As Geetha and Velraj (2012) suggest, these techniques can be classified into: (i) heat prevention and reduction, (ii) thermal moderation, and (iii) heat dissipation (In-depth explanations of these strategies can be obtained from Geetha and Velraj (2012).
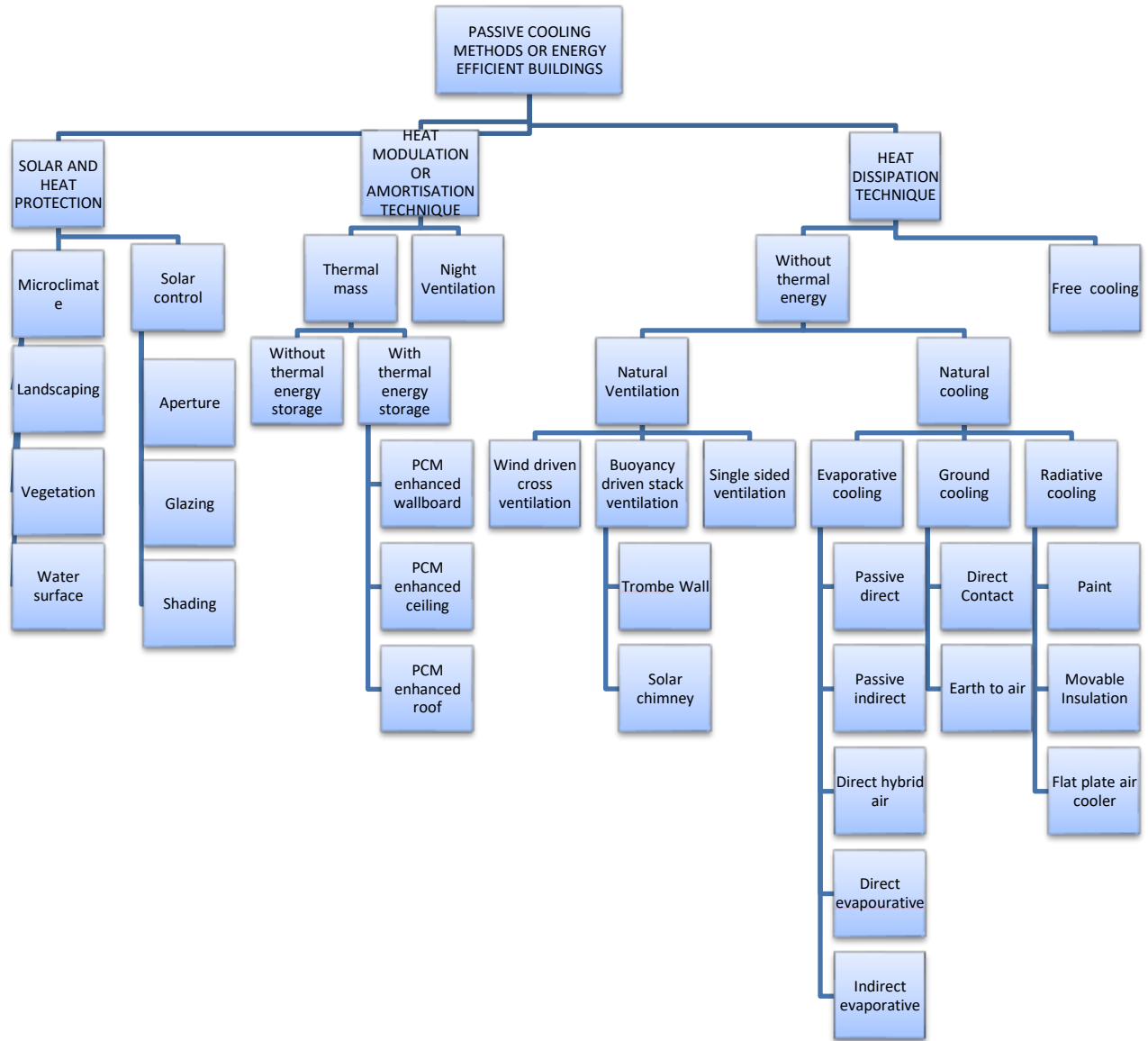
Figure 1: Classification of passive cooling methods on a Micro level

Figure 1 shows the array of methodologies used for passive cooling in buildings. It also shows that for this to be achievable there is a clear focus on design and practice. Take for example natural ventilation, the major function and advantage is the reduction of indoor temperature through the utilisation of natural airflow. This is in addition to improvement of thermal comfort, air quality and health. Various methods of natural ventilation techniques exist, which are majorly categorized as stack and cross ventilation

techniques. Stack ventilation, which relies on temperature difference inside and outside, also provides robust control of air flow and when applied properly provides superior air quality as compared to conventional mixing systems. On the other hand, cross ventilation can induce stronger air movement inside the building as opposed to stack; thus, improving air exchange, air quality and reducing the need for mechanical units (Aynsley 2007; Dimoudi 2009; Dehghani-sanij, Soltani et al. 2015). From another perspective, important questions of design and practice need to be asked, for examples: is the area of building development noisy? And are there high levels of air pollution in that vicinity? The reason for this question is that the amount of noise and quality of air would play a significant part in passive design considerations, invariably limiting ventilation options. These implications gives rise to an additional by product, which is the health implications of improper ventilation (Holmes and Hacker, 2007; Zhai et al 2011).

As regards the by-product, the building sector is strongly known for its association with issues related to health and wellbeing of cities (Sundell et al, 2011). Developing nations, in particular, are identified to live in low quality buildings; thereby, have higher negative health impact on the residences due to the low and adverse environmental standards. In fact slums, which are regular types of settlement in developing nations, have various health risks when exposed to unsanitary housing and indoor air pollutant (Ahmad and Puppim de Oliveira 2015). The health effects are not strictly for slums but rather affect an array of buildings. Previous studies by WorldGBC, (2014) have observed that the design of office buildings may have significant impact on occupant's health and wellbeing. Another investigation shows that good air quality leads to reduction in absence of employees due to health issues (Balaban and Puppom de Oliveira, 2015). Using Singapore as a case study in their research De dear et al (1991) declared that naturally-ventilated buildings had caused lower thermal discomfort when compared to air-conditioned buildings. This was due to the fact the air-conditioned buildings were over cooling causing up to 33% discomfort.

Thus, this issue not only suggested a health hazard but the concept of policies steps in, as this becomes relevant to support more stringent alternatives to cooling as well as curtail cooling excesses.

Another dimension of spatial level exists in terms of neighbourhood or meso scale. Various reports have highlighted the effects of urban geometry on energy consumption of which ranges by approximately 10% (Ratti, Baker et al. 2005). The ideology is that urban form for single building energy consumption can be observed to be meaningless; but across a spectrum of buildings, it holds considerable impact. Communities and neighbourhoods developed in this manner stand to gain significantly not only from energy consumption internally but also from external energy consumption. This is due to place making of amenities, which invariable affects the mode of transport in vicinity (Johansson 2006; Pirjola, Lähde et al. 2012). Strictly focusing on passive cooling, a lot of opportunities exist to enhance not only energy reduction initiatives but the improvement of air and health quality within the community scale. Taking the residential sector for example, Ko (2013) highlights an important finding in city planning in the US, between 1970's to 1980's, where urban form became an important dynamic to consider in energy conservation and site designs for community plans. Factors such as street orientation, density configuration, tree size and ground coverage became additional concepts to urban planning. As such more south facing buildings were developed with an east to west street orientations (Ko 2013). Tree planting was also introduced on community scale as an effective means to reduce energy for cooling and heating energy as well as to temper the UHIE. Also, the placement of deciduous trees on the west side of houses proved advantageous as it provided shade during summer and solar radiation in the winter. The concept of planting trees and shrubs is also hailed to be cost effective and energy efficient, most especially in hot and dry regions (Hildebrandt and Sarkovich, 1998; McPherson and Rowntree, 1993; McPherson and Simpson, 2003). These techniques, in modern times, are known as GI and possess the ability to regulate climate effects both indoors and outdoors through buffering solar radiation, lowering wind speeds and

evapotranspiration process. Additional effects include the removal of air pollutants by dry deposition and removal of smog formation, and thereby, improving the air quality (Wang, Bakker et al. 2014, Chen 2015).

The array of design alternatives such as mass tree planting in streets and parks as well as wider streets to promote natural ventilation and solar access cannot be emulated by micro level operations. Also the wider effects of ventilation is based not only on building orientations but streets, building height, compactness, density and mass utilisation of GI; all these have significant impact on ventilation (Jabareen, 2006; Ignatius, Wong et al. 2015). Taking compactness for example, in most research studies, it is argued that compactness prioritises energy implications of transportation and connectivity before ventilation, thus neglecting the wider implications of passive ventilation (Owens 1986; Holden and Norland 2005; Jabareen, 2006). Compactness is synonymous with heat gain from clustered buildings and people, which ultimately leads to higher cooling demand (Nuruzzaman 2015). Compactness is also synonymous to poor air quality and pollution not necessarily from vehicles but from the congestion, i.e. from conglomeration of people and buildings, as well as types of buildings stacked together. This often occurs due to lack of provision of ventilation channels as well as reduced green corridors and spaces (Holden and Norland 2005). Compact design also has higher chances of being affected by the UHIE due to less convection, more heat absorption, more CO_2 emissions and more use of air-conditioning (Sailor 2006; Nuruzzaman 2015). From a regional perspective, compactness in hotter climates further exacerbates temperatures and increases thermal load (Dursun and Yavas 2015). In cold regions, compact layout blocks solar access, making the demand for energy use higher through lighting and heating. It also reduces the effectiveness of certain GI due to high H/W, thus reducing solar access to GI of the built environment (Nuruzzaman 2015). As such, the example here gives the understanding of how the dynamics of ventilation changes when viewed from a higher spatial order. Therefore, it is clear that each spatial level is plagued with its own set of opportunities and challenges. Hence, the question here is not necessarily about spatial level of passive cooling techniques that are better than the other. In contrary, the question is, in fact, how can the various levels operate in

such a way as to complement each other and what are the elements in each system that make the application on each level a success or failure. This then leads to the investigation of the macro level or city-wide level, which tends be seen as a more complex level.

At the city level, the prediction is that about 6.3 billion people would reside in cities by 2050. This forecast of urbanisation growth is a strong motivation to actively plan and make the urban environment more liveable. Of course this has to be done while considering the energy conundrum currently plaguing the planet. All the while, addressing and maintaining significant levels of comfort within these cities (Lehmann, 2015). At all spatial levels, different elements have been considered to elucidate how thermal comfort in the form of cooling can be attained. This has been done with the prerequisite that buildings, streets and associated environments should be designed in such a way as to minimise energy consumption and fossil energy use (Jabareen, 2006; Geetha and Velraj 2012). The macro level could be seen as an aggregation of meso level neighbourhoods of an entire system that is controlled by a larger governing system. From a passive cooling perspective, one of the most identifiable macro level challenges is the effect of UHIE, which is further exacerbated due to the global warming projections threatening to further increase the global temperature. UHIE refers to cities exhibiting greater temperature increase in its centre than the surrounding rural areas (Yamamoto 2006). This has led to city-wide or macro urban cooling approaches to address UHIE and associated issues. The causes of UHIE have been attributed to Low albedo materials, human gathering, increased use of air-conditioning, destruction of trees, urban canopies, wind blocking densely situated buildings and air pollution from vehicles (Nuruzzaman, 2015). These causes have led to the associated effects of UHIE shown in figure 2. As can be seen, energy consumption, environmental pollution, human health and thermal comfort are causal effects of UHIE.
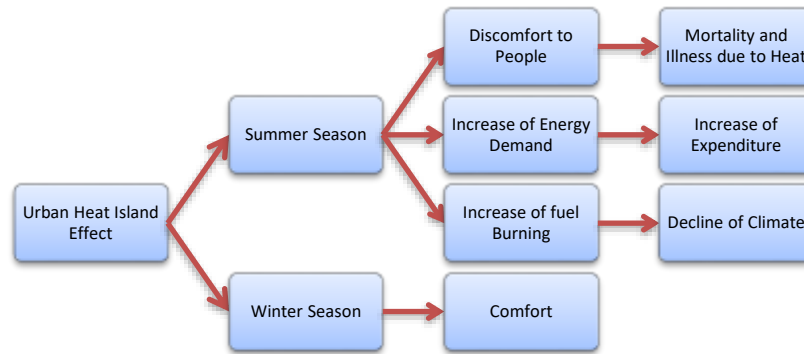
Figure 2: Effects of UHIE (adapted from (Nuruzzaman 2015))

These causes and effects have led to the development of two major cooling strategies, which are currently being utilised in a number of cities. The first strategy involves the increase of urban reflectivity and the second increases urban vegetation, otherwise known as GI. Other measures to passively cool and address this situation are illustrated below. Irrespective of this, other issues exist. These include factors such as orientation and design, which are essentially similar to the meso level but occurs at a much larger level, where issues such as urban canyon-effect needs to be considered. Urban canyon is the man-made version of the canyon but instead of rocky hills forming a crater that promotes rapid air flow, cities have high density and tall buildings providing the same effect. Urban canyons are often effective at macro scale. In the case, where the prevailing wind direction is in parallel to the urban canyon, wind speed increases resulting in provision of better ventilation. Due to this channelisation effect, this can also remove/flush out air pollutants (Spirn 1986; Kastner-Klein, Fedorovich et al. 2001; Pirjola, Lähde et al. 2012). Furthermore, in the geometry of canyons, height-width ratio is deemed as the main factor and can affect variation in wind leading to temperature difference of up to $5^°$C (Johansson 2006). On the contrary, urban canyons are direct contributors to the UHIE and temperatures within the canyon can be elevated to between $2^°$C to $4^°$C (Nunez and Oke 1977). Moreover, when tall buildings are adjoined with narrower streets, it is more likely to have poor wind flow and higher temperature (Kanakita, Singh et al. 2015). As a

result, deep canyons tend to be cooler in winter with shallower canyons being the more favourable adoption with particular ability to provide more solar access (Johansson 2006).

It is worth considering that these mitigation strategies (if to be implemented) for some of these challenges need to be supported at some level by policy and regulations, especially for macro scale passive cooling techniques. A good example is the reflective surfaces, by painting the roof white or other more reflective colours, UHIE can be reduced at the city scale. This effect occurs due to the increase of reflectiveness of urban surfaces, thus removing solar radiation that would otherwise be converted into heat. However, without policies in place for the enforcement of unanimous change to a more reflective colour, the idea of reflective surface becomes redundant (Moonen et al, 2012). Take for instance the city of Bermuda where roofs and buildings are white or reflective in nature with an abstinence from dark colours. The perceived advantage here is overall conformity of households to these colours [60]. Nonetheless problems do exist, such as, the visible dust and maintenance cost that may be incurred for such strategy. However, at a larger scale this may be economical when energy savings are estimated.

Methodology

By extensively analysing the literature on passive cooling techniques, this study divides these techniques into three levels of macro, meso and micro. Moreover, through the literature review, five essential components were deduced to affect passive cooling at all three spatial levels. These components are: 1) design and practice, 2) environmental implication in terms of greenhouses gases and pollution, 3) energy consumption, 4) health and welfare implications, and 5) the institutional backing required, i.e. policy and guidelines. These elements were determined to be recurring principles in the design of passive cooling techniques at all three spatial levels. As mentioned earlier the question is not necessarily which level addresses passive cooling optimally but rather what combinations of levels and what strategy under each level would work the best or even hinder passive cooling techniques and implementation. To execute this,

a SWOT analysis of all three levels is proposed to put into perspective the capabilities of each level in addressing passive cooling.

At first, the literature has identified all available passive cooling energy systems at three spatial levels (as shown in Table 1 below). These are identified as 5 macro-level systems, 6 meso level systems, and 12 micro level systems. In the next step, the SWOT analysis is conducted individually to provide an overview of each passive cooling energy system. These leads to further evaluation of systems at their respective spatial levels. By doing so, the aim is to identify and cross-evaluate which strengths, weaknesses, opportunities and threats are the most or the least inherent at each spatial level. The findings provide designers and even policy makers a better picture in their choice of passive design either for communities or cities that want to embark on this concept, or the optimisation of already-developed techniques, or for home owners and private architects who want to optimise their personal homes and projects.

Table 1 - Passive Cooling Energy Systems at Three Spatial Levels

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. Desiccant Cooling
		12. Building Envelope

A review of 75 different literature sources with direct reference to each level was used to identify and categorise information. The sources were extracted from three main body of journal articles, namely Science Direct, Google Scholar, and Web of Science. The literature that had explicit information on the five essential indicators of: 'practice (PR)', 'Health (H)', 'Environment (EN)', 'Energy (EG)', and 'Policy (PO)', was prioritised. As explained earlier in the introduction section, these five indicators represent the whole spectrum of implications in the current literature. It is also important to note that practice includes design indicators in the sector of the built environment. In this study, two indicators of 'economic' and 'social' are wittingly excluded in order to have a stronger focus on energy systems and energy use reductions. Later, the studied indicators are used in the matrix to discuss issues of implementation and application for energy-use reductions. Study stopped when no new information or innovation could be obtained on the mechanisms of the three spatial levels; i.e. nothing more could be obtained on urban geometry, urban canyon, density, solar shading, etc.

Finally, this assessment is based on the verification of two most significant indicators pertinent to the scope of study of each literature as some of the passive energy systems can comprise of several indicators. It is improbable to totally remove subjectivity from a SWOT analysis; however, this was mitigated to a minimum by cross referencing information with similar authors in the field. For this reason, debatable indicators have two, three or even four references to support their positions. The SWOT analysis is developed as the primary method for the study's analysis as it offers cons and pros of each passive energy system, which is essential for the later assessment in this study and future research. Following from the SWOT analysis, the study utilises the results to develop an indicator-based matrix of SWOT analysis. The proposed matrix is

developed by first accumulating the total number of all five essential indicators (PR, H, EN, EG, and PO) against the conducted SWOT analyses at each of three spatial levels. This analysis is expected to highlight the main gaps and strengths of each spatial level, which is indeed a useful result that can only be obtained from such comprehensive SWOT analysis study. Then, the results obtained from this indicator-based analysis provides a review of each studied spatial level individually, before the study offers a further discussion regarding the overlap between these spatial levels. In summary, the study approach the passive energy systems analyses from (1) individually for each system (through SWOT analysis), towards (2) for each spatial level against five key indicators, and then (3) overview of each spatial level to a complete picture of all three spatial levels of the built environment. The following section represents the first step that addresses the SWOT analysis of passive energy systems with brief description of each element.

SWOT Analysis Results

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

The five identified passive cooling energy systems at macro level are: (1) Urban Geometry & Patterns, (2) Urban Canyons; (3) Urban Cool Islands (UCIs), (4) Green Infrastructure (GI), and (5) Bioclimatic Planning & Design (BPD). The below results are extracted from the studies of Dawodu and Cheshmehzangi (2017), which are utilised for this multi-spatial and multi-indicator evaluation. See table 1 for further details and cross reference.

> ***1. Urban Geometry and Patterns***

Strengths - Increase of wind field and speed (PR/PO); Hierarchy of heights for prevailing winds (PR/PO); Channelisation of prevailing wind flow (PO) (Zhang, Gao et al., 2005, Ng, 2009).

Weaknesses - Penetration through the urban fabric (PO); Streets not aligning accordingly (PR); the blockage effect (PR) (Ng 2009).

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) (Zhang, Gao et al., 2005, Ng, 2009).

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) (Hu and Ng, 2009, Dawodu and Cheshmehzangi, 2017).

2. *Urban Canyons*

Strengths - Channelisation and removal of air pollutants (H/EN); Temperature reduction (PO/EG) (Spirn 1986; Kastner-Klein, Fedorovich et al. 2001; Johansson, 2006).

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) (Nunez and Oke 1977; Spirn 1986; Kastner-Klein, Fedorovich et al. 2001; Johansson, 2006; Pirjola, Lähde et al. 2012).

Opportunities – Mandatory implementation of air ventilation (PO); Assessments optimisation or maximisation of air ventilation through urban fabric (PR/PO) [62] (Ng, 2009).

Threats – Potential channelling of air pollution downwind (PR/EN) (Spirn, 1986; Dawodu and Cheshmehzangi, 2017).

3. *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); Channelisation of wind paths (EN/PR); Alleviation of air pollution (EN/H) (Yamamoto,2006).

Weaknesses – N/A

Opportunities – Mitigation of health implications of UHIE (H) (Yamamoto,2006; Doick and Hutchings, 2013).

Threats – Dark surface heat storage (EN); Minimised vegetation in cities and UHIE (EN/H) (Yamamoto,2006; Doick and Hutchings, 2013, Dawodu and Cheshmehzangi, 2017).

4. *Green Infrastructure (GI)*

Strengths – Minimisation of thermal absorption (PO); Storm water runoff attenuation (PO); Reduction of UHIE (PO/PR); Pollution control (PO/EN) (Clark et al. 2010; Chen, 2015).

Weaknesses – Lack of eco-system design standards (PO); Time factor for maturity (PR); High levels of water requirements (EN) (Norton et al. 2015).

Opportunities – Native/local plant species (PR/PO); Utilisation of GI in planning and design (PO/PR) (Clark et al. 2010; Norton et al. 2015). .

Threats – Lack of understanding of eco-system control variables (PO/EN); Significant Seasonal variations (EN); Insect invasions (H); Issues of turbulence on plant species (EN/PR) (Hunter et al. 2014, Dawodu and Cheshmehzangi, 2017).

5. *Bioclimatic Planning & Design (BPD)*

Strengths – Use of climate and environmental conditions (EG); Reduction of dependency on mechanical systems (EG); Biomimicry (PR/EN); Solar radiation control (H/EG); Dust control (H/EG); Evaporation control (EN/H); Water control (PO/EN) (Attia and Duchhart, 2011; Țundrea, 2013).

Weaknesses – Lack of integration in planning and design (PR/PO) (Attia and Duchhart, 2011; Țundrea, 2013, Dawodu and Cheshmehzangi, 2017).

Opportunities – N/A

Threats – N/A

B. SWOT Analysis of Passive Cooling Energy Systems at Meso Level.

The six identified passive cooling energy systems at meso level are: (1) Urban Layout (Configuration), (2) Density; (3) Orientation (Passive Solar Cooling), (4) Compactness, (5) Construction Materials, and (6) Green Infrastructure (GI). The below results are extracted from the studies of Dawodu and Cheshmehzangi (2017), which are utilised for this multi-spatial and multi-indicator evaluation. See table 1 for cross reference.

1.   Urban Layout (Configuration)

Strengths – Wide streets design improving air flow (PR/PO); Advantageous utilisation of street canyon effect (PR); Hierarchy of heights for prevailing winds in narrow winding streets for hot dry climates (PR/PO); Hierarchy of heights allows for building shading (PR/PO) (Hough, 1995; Golany, 1996).

Weaknesses – Wider streets allow greater solar access (PR/PO) (Ko, 2013).

Opportunities – Understanding the pitfalls in design and practice, opportunities for better layouts and design become apparent (PR) (Givoni, 2009; Cheshmehzangi and Butters, 2017).

Threats – Windblown dust in hot dry climates (EN); Delicate building placements (PR) (Golany, 1996; Givoni, 2009).

2.   Density

Strengths – Low density configuration reduce UHIE (PR/EN) (Ko, 2013)

Weaknesses – Dense development emit more heat than less dense (EN); Reduced thermal comfort especially in tropical cities with dense design (H/EN); Less available ground level wind for dense design

(PR/EN); Lack of gaps and open spaces reduces air volume (EN/H); Building obstruction in breeze and pathway (PR) (Ng, 2009; Ko, 2014; Cheshmehzangi and Butters, 2017).

Opportunities – Avoidance of perpendicular airflow against high identically heighted buildings (PR) (Givoni, 2009).

Threats – Direct competition with solar access (dense design) (PR), Formation of wind barriers (PR), Promote UHIE (EN/H), Avoidance of perpendicular airflow against high identically heighted buildings (PR) (Khaled, 1996; Givoni, 2009).

3. *Orientation (Passive Solar Cooling)*

Strengths – Increased wind speed with parallel wind orientation (PR) (Givoni, 2009).

Weaknesses – Street ventilation blockage due to Wrong orientation (PR); Low Aspect Ratios (H/W); Promotes higher light penetration (PR) (Shashua-Bar, L. and M. E. Hoffman 2003; Givoni, 2009)[31];

Opportunities – Optimising building placement (PR); Manipulating solar access with building placement (PR); Manipulating solar access with street orientation (PR) (Ko, 2014).

Threats – Complication between solar penetration and ventilation air flow (PR) (Ko, 2014).

Compactness

4. Strengths – N/A

Weaknesses – Transport focus design neglecting ventilation (PR/PO); High cooling load demands due to heat gains (EG); Poor air quality and pollution (H/EN); Higher chances of UHIE (EN/H); Regional incompatibility promoting higher thermal loads (EN/EG); Renders GI ineffective (PR/EN) (Holden and Norland, 2005; Jabareen, 2006; Dursun and Yavas 2015; Ignatius et al. 2015)

Opportunities – Utilisation of dispersed configuration (PR/PO) (Dursun and Yavas 2015).

Threats – Compact configuration versus dispersed (PO/EG) (Khaled, 1996; Ko 2013; Dursun and Yavas 2015).

5. Construction Materials

Strengths – Use of lighter coloured surfaces to reduce cooling load (PR/EN); Use of lighter coloured surfaces to reduce UHIE (PR); Reduction in solar energy absorption (PR) (Khaled, 1996; Kanakita, Singh et al. 2015)

Weaknesses – Increased UHIE due to darker materials (PR/EN); Increased cooling load due to darker colours (EG); Increased storm water runoff temperature (EN) (Yamamoto, 2006; Kanakita, Singh et al. 2015).

Opportunities – Replacing impermeable pavements with permeable pavements (PR) (Khaled, 1996)[72].

Threats – Aesthetical barrier (PR); Inability to hide dirt, moss and other weathering characteristics (darker roofs) (EN); Glare over reflective surfaces (PR/PO); Lack of policy implementation (PO) (Sailor, 2006; Shickman, 2014).

6. Green Infrastructure (GI)

Strengths – Reduction in UHIE through shading and evapotranspiration (EN/EG); Cooling buildings and improving thermal comfort (EG/H); Improved effectiveness of cooling through evapotranspiration (EG); Reduction in wall temperatures through vines and shrubs (EG); Combined implementation of GI And material selection foe effective cooling load reduction (PR/EG); Limitation of air pollution (EN/H) (Akbari et al 2001; Doick and Hutchings, 2013; Shickman, 2014).

Weaknesses – Improper placement of trees leading to wind blockage (PR); inefficient tree configuration (PR); Lack of industry standards (PR/PO) (Ko, 2013; Chen 2015).

Opportunities – Tree selection and configuration (PR/EG); Strong heath impact (EN/H); Tree size and water management (PR/EN) (Hildebrandt and Sarkovich, 1998; McPherson and Rowntree, 1993; McPherson and Simpson, 2003; Doick and Hutchings, 2013; Ko, 2013)

Threats – Improper tree placement (PR/EG); Lack of understanding of tree functions and anatomy (PR); Lack of understanding of tree tolerance (PR); Wrong balance between GI and built environment (PR/EN) (Hildebrandt and Sarkovich, 1998; McPherson and Rowntree, 1993; McPherson and Simpson, 2003; Doick and Hutchings, 2013; Ko, 2013).

C. SWOT Analysis of Passive Cooling Energy Systems at Micro Level

The 12 identified passive cooling energy systems at micro level are: (1) Solar Shading, (2) Greening (shading); (3) Thermal Mass and Materials, (4) Insulation, (5) Solar Chimney, (6) Air Vents/Natural Ventilation, (7) Wind Towers, (8) Radiative Cooling, (9) Evaporative Cooling, (10) Earth Coupling (Earth Cooling), (11) Desiccant Cooling, and (12) Building Envelope. The below results are extracted from the studies of Dawodu and Cheshmehzangi (2017), which are utilised for this multi-spatial and multi-indicator evaluation. See table 1 for cross reference.

1. Solar Shading

Strengths – Materials shading (PR/EG); Shading by overhangs louvers and awnings (PR/EG); Shading by roof (PR/EG); Shading by trees and vegetation (PR/EN); Glazing: Temperature Control (PR/EG) (Geetha and Velraj, 2012)**.**

Weaknesses – Design implication for colder climates (PR/EG) (Dubois, 1997).

Opportunities – Utilisation of greening for shading (PR/EN) (Kamal, 2012).

Threats – Lack of microclimate understanding (PR); Lack of solar design understanding (PR); No universal best practices method (PR) (Geetha and Velraj, 2012; Kamal, 2012; Dubois, 1997).

2. Greening (shading)

Strengths – Green shading and evapotranspiration (EN/EG); Wind modification/vegetation control (EN); Alternative and combined options for utilisation (PR/EN) (Geetha and Velraj, 2012; Chenari et al. 2016).

Weaknesses – Improper placement of greenery trees (PR) (Ko, 2013).

Opportunities – Optimising tree function by proper understanding of tree positioning, structure and anatomy (PR) (Geetha and Velraj, 2012; Balaban and Puppom de Oliveira, 2015).

Threats – The lack of understanding of the stated opportunities would be significant threat to ability to use the green function (PR).

3. Thermal Mass (construction Materials and Phase change materials)

Strengths – Pre-night cooling of buildings (PR/EG); Shifting of day heat to night for removal (PR/EG); Thermal management through understanding and regulating mass in construction materials (thermal mas for load shifting) (PR/EG); Use of high mass buildings and exhaust fans for night cooling in hot humid regions is more advantageous than lightweight materials. (PR/EG) (Kamal, 2012; Osterman et al. (2015).

Weaknesses – Load shifting may be difficult execute in domestic buildings where there is constant occupancy (PR/EG); Improper use of material may lead to thermal gains and discomfort (PR/EG); Improper use of material may lead to discomfort and wellbeing (H) (Geetha and Velraj, 2012; Kamal, 2012; Osterman et al. 2015).

Opportunities – Utilisation of thermal mass using Phase Change Material (PCM) (PR/H); Proper understanding of PCM in windows, walls and roofs & ceilings (PR/EG) (Geetha and Velraj, 2012; Kamal, 2012).

Threats – Inadequate understanding and planning of load shifting (PR); Heavily dependent performance of the building (EN/EG) (Santamouris and Wouters 2006; Geetha and Velraj, 2012; Kamal, 2012)

4. Insulation

Strengths – Limiting thermal Penetration (PR/EG); Reduction of draught (PR/H); Resistant to negative microclimate effects (PR/EN) (Geetha and Velraj, 2012; Kamal, 2012).

Weaknesses – Improper application of insulation material (PR) (Geetha and Velraj, 2012; Kamal, 2012).

Opportunities – Proper understanding the material used (PR) (Geetha and Velraj, 2012).

Threats – Improper use of the volume and materials for insulation (H) (Geetha and Velraj, 2012; Kamal, 2012).

5. **Solar Chimney**

Strengths – Utilisation of solar energy for ventilation (PR); Ensures interior air quality is maintained. (PR/H); Quicker air change rates than other natural ventilation designs (PR/H); Good alternative against micro-climatic factor of wind availability (PR/EN) (Dimoudi, 2009; Zhai et al. 2011).

Weaknesses – Heavily Dependent on the predictability and availability of solar radiation (EG) (Dimoudi, 2009; Sadineni et al. 2011).

Opportunities – Understanding ventilation control (PR); Understanding and maximizing temperature difference (PR); Hotter climactic advantage if applied properly (PR) (Sundell et al. 2011).

Threats – Lack of understanding of design control and implementation (PR/EG) (Sundell et al. 2011; Zhai et al. 2011)

6. **Air Vents/Natural Ventilation**

Strengths – Utilisation of Natural airflow (PR/H); Existence of well-established methodologies (PR); Flexibility in design selection and control (PR) Predictable performance (PR); Superior and diversity in air quality control (PR/EG); Utilisation of curved roof vents (PR); Well established best practices (PR) (Santamouris and Wouters, 2006; Aynsley, 2007; Kamal, 2012).

Weaknesses – In humid climates, natural ventilation increases indoor humidity (H) (Aynsley, 2007; Taleb, 2014).

Opportunities: Proper understanding of ambient conditions (PR); Proper understanding of design strategy utilisation (PR); Location specific implementation of combined natural ventilation strategies such as cross or stack ventilation (PR) (Chenari et al. 2016).

Threats – Extreme climactic factors and unpredictability EN, Difficulty in natural ventilation strategy prediction (PR); Complexities in design require specialist understanding (PR) (Taleb, 2014; Dehghani-sanij et al. 2015).

7. Wind Tower

Strengths – Can be re- oriented or multisided in design to maximize wind flow, thereby improving ventilation (PR); Easy to construct (PR); Integrated principled of traditional wind towers with modern technology (PR) (Hughes et al. 2009; Dehghani-sanij et al. 2015).

Weaknesses – Susceptible to dust, other particulate matter and insects (H) (Dehghani-sanij et al. 2015).

Opportunities and Threats – NA

8. Radiative Cooling

Strengths – Movable insulation (PR/EG); Utilisation of Diode roof (PR/EG); Utilisation of Roof pond (PR/EG); Paint utilisation (PR/EG) [9][10].

Weaknesses – Heavily microclimate dependent (EN) [9][10].

Opportunities and Threats – N/A

9. Evaporative Cooling

Strengths – Green utilisation (PR/EG); Water control and utilisation (PR/EN); Material augmentation (PR/EG); Dust control (PR/EN); Utilisation of solar heaters (PR/EG) (Geetha and Velraj, 2012)

Weaknesses – Lack of efficiency in operation in humid climates but rather best in dry climates (EN) (Geetha and Velraj, 2012)

Opportunities – Proper understanding of evaporative functions and options thus more effective utilisation (PR/EN) (Okba, 2005).

Threats – Lack of understanding of evaporative functions especially in hotter climate zones (PR/EN) (Okba, 2005).

10. Earth Coupling (Earth Cooling)

Strengths – Provides low constant temperature due to constant earth or soil temperatures (PR); Reduction in air infiltration (PR/H); Acts as a thermal mass (PR); It has the advantage of reducing solar and convective heat gains (EG); Less impacted by outdoor climactic fluctuations (EN) (Geetha and Velraj, 2012; Kamal, 2012).

Weaknesses – Difficult to implement due to the contextual nature, design from climatic and environmental perspective and structural design (PR) (Geetha and Velraj, 2012; Kamal, 2012).

Opportunities – Regional variations in utilisation and application of technique (PR); Proper knowledge of soil and surrounding earth landscape (PR) (Geetha and Velraj, 2012; Kamal, 2012).

Threats – Proper understanding of design parameters is critical for the benefits of this configuration and so is the lack of (PR) (Geetha and Velraj, 2012; Kamal, 2012).

11. Desiccant Cooling

No literature were found that identity or suggest strengths, weaknesses, opportunities, and threats of 'Desiccant Cooling'. Hence this section is blank.

12. Building Envelope

Strengths – Maximising advantage of building orientation (PR); Maximising the use of cross ventilation (PR/EN); Efficient use of construction materials (PR/EG); Reduction and reflectivity of ground surfaces

(PR/EG); Maximising building internal volume and limiting wall barriers (PR) (Okba, 2005; Sadineni et al. 2011).

Weaknesses – Conflict between natural ventilation and other building requirements such as sound considerations (PR) (Okba, 2005; Sundell et al. 2011)

Opportunities – Orientation and shape of building to avoid direct solar radiation (PR/EG) (Sadineni et al. 2011).

Threats – Utilisation of reflective walls (PR/EG); Optimisation of building location orientation and volume (PR) (Sadineni et al. 2011).

Cross Analysis at three Spatial Levels for Energy-Use Reductions

As shown in the comprehensive SWOT analysis in the previous section, this evaluation approach (Dawodu and Cheshmehzangi, 2017) provides an overview of available passive cooling energy systems individually and at each spatial level of macro, meso and micro. Based on their specific implications, we can argue for the feasibility of each system for the benefit of energy-use reductions. Some applications are not necessarily complicated or technologically advanced, but are rather important for utilisation at particular spatial levels of the built environment (Cheshmehzangi and Butters, 2017; Dawodu and Cheshmehzangi, 2017). In this study, we review and evaluate these implications through five primary indicators of 'Practice (PR)', 'Health (H)', 'Environment (EN)', 'Energy (EN), and Policy (PO). The figures are accumulated for each indicator at each spatial level. The below table, demonstrates the matrix for this assessment.

Table 2 – Indicator Matrix of SWOT Analysis

	Macro					Meso					Micro				
	PR	H	EN	EG	PO	PR	H	EN	EG	PO	PR	H	EN	EG	PO
S	6	6	8	5	11	10	2	4	5	3	43	5	10	21	0
W	7	1	5	0	3	10	4	10	4	3	7	3	2	4	0
O	6	2	0	0	8	8	0	2	1	1	15	1	2	2	0
T	4	3	7	0	3	10	1	4	2	3	10	1	3	3	0

The below findings highlight specific spatial levels of macro, meso, and micro, which are extracted from the earlier study on passive cooling energy systems by Dawodu and Cheshmehzangi (2017). This overview highlights the specific evaluation of each spatial level on their own before we could suggest overlaps and connectivity between the three spatial levels of the built environment.

Macro Level Review - The results in the above lends further understanding to challenges and successes of passive ventilation systems (Dawodu and Cheshmehzangi, 2017), if and when utilised. From a macro level standpoint the major strengths lay within its policy implementation, as this was seen to have a stronger and wider effect on implementation. However, weaknesses were derived more from a practice perspective, which are consistent with all three scales. This indicates the importance of design and code of practice, an aspect of the built environment which is known to be lacking in a lot of developing nations. Thus, the argument could then be from a macro level, that effectiveness on its utilisation within developing nations is largely dependent on policy implementation on city-wide scale and the development and enforcement of building and street codes and guidelines for ventilation in addition to predesign assessments (such as air ventilation assessment) of greenfield sites or brown and infill sites. In addition, the health and environmental implication are catered to more on a larger scale as results show that strengths lie in this area and this is largely due to GI implementation and mitigation of UHIE effects. However, it is important

to note the interplay between policy and the other indicators; for instance, the use of reflective materials is known to reduce energy consumption in buildings on micro level but with no policy-based incentive or inducement this would be extremely difficult on a macro scale. These arguments hold the same with GI and tree implementation, which should be further governed by the right or best code of practice. The strength of the macro-level is accrued mainly from the efficacy of policy implementation, however, as this study has shown, a major challenge in developing nations seems to be the apparent disjoint between policy and the implementation of this policy (in design and practice). Thus. it could be inferred that the utilisation of the strength of the macro-scale is burdened by its limitations hence its potential might not be wielded effectively. Nonetheless, understanding these linkages is critical to its implementations especially within hot dry and humid regions where ventilation and cooling has severe social, environmental and energy implications (Dawodu and Cheshmehzangi, 2017).

Meso Level Review - The results on meso level is significantly different from the macro Level and has less of a policy influence in its success (Dawodu and Cheshmehzangi, 2017). However, this is still an aspect to consider as micro level lacks policy motivations entirely. There is a strong contribution of design and practice in its success and failure, with the strengths largely stemming from GI and the layout of the site. Again this is understandable as these two facets have been observed to affect the environment significantly, with GI addressing UHIE, air quality, street and also building thermal comfort and also aids in channelisation of wind. As for urban layout, this is largely focused on wind availability and channeling of wind and it is quite reasonable for the strengths to lie in location and layout as the famous quote "location is everything" lends strength to this. What's particularly interesting about the meso level is that its weakness, which is the highest across all levels, is practice and energy oriented and the source lies within density and compactness. This is quite important to note due to the on-going debates in various literature regarding these configurations and what scale and configuration is ideal for development. However, most western

models have opted for the transportation focused configuration which is energy and socially oriented that is to say minimisation of transport fuel with compactness and utilisation of mixed use developments. However, from a ventilation and GI standpoint, this stands to have a negative impact on health and thermal comfort and indeed natural ventilation itself. As such, from a ventilation perspective a more dispersed configuration mixed with less dense buildings could be a valid recommendation which would have not only energy and environmental impact but also social, though it is clear that compromises need to make for its effective use. Nevertheless, the context of its utilisation needs to be added to the equation; for instance, in hot dry regions of the world where ventilation is critical to health and thermal comfort, should a transport-led design be prioritised? Or do we opt for a less congested dispersed approach promoting GI and meso ventilation strategies? Hence, the consideration of ventilation at the meso-scale lies in its contextual argument, practice orientation and policy backing (Dawodu and Cheshmehzangi, 2017).

Micro Level Review - The results of micro level analysis varies significantly from the other two levels. Practice and design show an overwhelming dominance in its utilisation as a passive ventilation technique (Dawodu and Cheshmehzangi, 2017). Policy plays no role in its implementation. Another important discovery is the strong link between practice and energy when considering its strength. This is not to say other parties do not play significant roles. The basis of the qualitative SWOT analysis was based on the underlying reasoning's for each passive ventilation techniques. For micro, it was largely observed that a lot of the strengths were practice and design focused but energy driven, which though not part of the scope of this study hold economic as well as environmental importance. It is also clear that policy implementation does not specifically hold strong sway over the utilisation of any specific passive system but rather it is based on design and practice indicator as well as the energy and environmental prerogative (Dawodu and Cheshmehzangi, 2017).

Unlike meso and macro levels which promote ventilation through wind speed and channelisation in both buildings and streets, micro level did not have to contend with both scopes (Dawodu and Cheshmehzangi, 2017). Moreover, it was discovered that micro level largely dealt with limiting thermal penetration; thus, thermal resistivity was the main focus of most aspects of the SWOT as compared to meso and macro, which promoted both air flow and thermal resistivity. This thermal design focus led the major weaknesses on the micro level to revolve around micro climate unpredictability and extremes. The advantages and weaknesses also had a lot to do with solar radiation and the manipulation of this renewable resource. In comparison, it is clear that the major strength within implementation is also its major weakness. As such, developing countries need to firstly understand and if not developed, develop building codes, guidelines and processes that aid the utilisation, as this is observed to be critical to its success or failure. This becomes certainly important in hotter regions where solar radiation is abundant; bearing in mind that application at micro level is largely governed by solar energy understanding and its exploitation (Dawodu and Cheshmehzangi, 2017).

Further Discussions: Three Spatial Levels Overlap

The comprehensive SWOT analyses, which were conducted in this study, not only highlight advantages and disadvantages of individual passive energy systems across three levels, but also help energy specialists, policy makers, planners and designers to evaluate how they can utilise them based on the key studied indicators. In this study, we explored these energy systems as methods of reducing energy use and lessening the dependency on active energy systems (Dawodu and Cheshmehzangi, 2017).

At macro level, we have consideration of practice and policy with substantial health-related issues. Also at macro level, there are more policy indicators than in meso and micro levels, meaning that the effectiveness

of policy development and implementation is higher at a larger scale. On the other hand, there were no policy indicators identified at micro level, while there is a very high tendency towards practice and design indicators. As a result, practice and design indicators are substantially more feasible and applicable at micro and meso levels (in comparison to macro level). Similarly, at micro level there are more energy indicators than in macro and meso levels; particularly that at micro level, energy indicators are limited to strengths. This partly is dependent on the numerous available passive cooling energy systems at micro level that are small-scaled, while at macro level passive energy systems are limited and often directed from policy (Dawodu and Cheshmehzangi, 2017).

In summary, we can argue for the interplay between spatial levels, where there are more effective implementation scenarios (for design and practice) at smaller scales in comparison with the importance of policy development at a larger scale. In addition to this, we can also argue in favour of meso and micro scales for the benefit of energy indicators and towards energy-use reductions. This is particularly significant for cooling, which is the main focus of this research study (Dawodu and Cheshmehzangi, 2017).

CONCLUSIONS

It is well established within this research study the positive impact of utilizing passive ventilation in cooling strategies, especially within hotter climate zones. It is also established that passive ventilation is an efficient way of reducing the load of active systems. Thus, before even considering active systems, passive systems should be the first point of call. From the indicator perspective, it is well understood that there is interplay between the practice and design, policy, environment, energy and health. The level of interplay was largely interpreted through qualitative categorisation and the use of SWOT Analysis. This helped a broader understanding that to what degree each passive system could contribute to energy efficiency and

sustainability in the built environment. This step was taken further at spatial level (macro, meso and micro), in order to evaluate how passive ventilation could then be maximised (Dawodu and Cheshmehzangi, 2017).

The results revealed the interdependency of each indicator, such as, how macro level strengths and weaknesses are embedded within policy and practice, and how Micro level was largely dependent on practice and had large energy dependent factors related to its strengths and weakness. However, the Meso level exhibited strong practice and design focus with considerations to environmental and policy driven indicators but were mostly plagued with contextual and biased factors in its implementation (Dawodu and Cheshmehzangi, 2017). The results also provide a holistic overview of each passive energy system as well as how they can be utilised for future research. This research demonstrate three sets of findings: (1) an individual SWOT analysis for each passive energy system, which represent the pros and cons of those identified systems in their respective spatial levels, (2) an indicator-based analysis of all three spatial levels against the SWOT analysis results, and (3) the comprehensive review of all spatial levels and their overlaps. Upcoming research can utilise results from this research in the following way: set (1) for future optimisation studies of those passive energy systems and helping designers and decision makers for their implications in practice; set (2) for future research on multi-indicator analysis of passive energy systems; and set (3) for future research on multi-level approach to passive energy systems and passive design strategies, including but not limited to a) development of integrated design methods, b) policy and regulation, and 3) holistic overview of the passive techniques, strategies, and systems.

Finally, as highlighted in the earlier study by Dawodu and Cheshmehzangi (2017), relating these results to developing nations, the meso scale though practically-oriented is able to be influenced moderately by policy. As such, it turns out that tractability could be easily achieved in the meso-scale, than in the macro-scale. This is specifically the case for the context of developing countries, not because pursuing a macro or micro scale initiative is inherently faulty; but because, the disjoint between policy and practice makes the case for a bias towards meso-scale implementation in developing nations. Interpreted further, micro scale

focus for passive ventilation systems in the urban setting is limited due to unpredictable and underdeveloped implementation of practice and design on a building to building bases, while macro scale need policy-driven frameworks to be fully advantageous; thus, making both lacking efficacy in developing nations, which are plagued with these direct issues .

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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