Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 105 (2017) 3411 – 3418

Energy Procedia

The 8th International Conference on Applied Energy – ICAE2016

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

Ayotunde Dawodu[a], Ali Cheshmehzangi[a,*]

[a]The University of Nottingham Ningbo China, 199 Taikang East Road, Ningbo, 315100, China

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.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.

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

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.
doi:10.1016/j.egypro.2017.03.780

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

pollution (EN/H) [10]. **Weaknesses –** N/A **Opportunities –** Mitigation of health implications of UHIE (H) [10][11]. **Threats –** Dark surface heat storage (EN); Minimised vegetation in cities and UHIE (EN/H) [10] [11].

- ***Green Infrastructure (GI):*** **Strengths –** Minimisation of thermal absorption (PO); Storm water runoff attenuation (PO); Reduction of UHIE (PO/PR); Pollution control (PO/EN) [12][13]. **Weaknesses –** Lack of eco-system design standards (PO); Time factor for maturity (PR); High levels of water requirements (EN) [14]. **Opportunities –** Native plant species (PR/PO); Utilization of GI in planning/design (PO/PR) [13] [14]. **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) [15].
- ***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) [16][17]. **Weaknesses –** Lack of integration in planning and design (PR/PO) [16][17] **Opportunities –** N/A **Threats –** N/A

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

- ***Urban Layout (Configuration):*** **Strengths –** Wide streets design improving air flow (PR/PO); Advantageous utilization 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) [18] [19]. **Weaknesses –** Wider streets allow greater solar access (PR/PO) [20]. **Opportunities –** Understanding the pitfalls in design/ practice, opportunities for better layouts and design (PR) [21]. **Threats –** Windblown dust in hot dry climates (EN); Delicate building placements (PR) [18][21].
- ***Density:*** **Strengths –** Low density configuration reduce UHIE (PR/EN) [20] **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)[20][2]. **Opportunities –** Avoidance of perpendicular airflow vs. high identically heighted buildings (PR) [21] **Threats –** Direct competition with solar access (PR), Formation of wind barriers (PR), Promote UHIE (EN/H), Avoidance of perpendicular airflow against high identically heighted buildings (PR) [21][22].
- ***Orientation (Passive Solar Cooling):*** **Strengths –** Increased wind speed with parallel wind orientation (PR) [21]**.** **Weaknesses –** Street ventilation blockage due to Wrong orientation (PR); Low Aspect Ratios (H/W); Promotes higher light penetration (PR) [21][23]; **Opportunities –** Optimizing building placement (PR); Manipulating solar access with building placement (PR); Manipulating solar access with street orientation (PR) [20]. **Threats –** Complication between solar penetration and ventilation air flow (PR) [20].
- ***Compactness:*** **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)[24][25][26][27]. **Opportunities –** Utilization of dispersed configuration (PR/PO) [24]. **Threats –** Compact configuration versus dispersed (PO/EG) [20][21][22][24].
- ***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) (Ng, 2009) [2][9]. **Weaknesses –** Increased UHIE due to darker materials (PR/EN); Increased cooling load due to darker colours (EG); Increased storm water runoff temperature (EN) [9][10]. **Opportunities –** Replacing impermeable pavements with permeable ones (PR) [2]. **Threats –** Aesthetical barrier (PR); Inability to hide dirt, moss and other weathering characteristics (EN); Glare over reflective surfaces (PR/PO); Lack of policy implementation (PO) [28] [29].
- ***Green Infrastructure:*** **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) [11][29][30]. **Weaknesses –** Improper placement of trees leading to wind blockage (PR); inefficient tree configuration (PR); Lack of industry standards (PR/PO) [20]. **Opportunities –** Tree selection and configuration (PR/EG); Strong heath impact (EN/H); Tree size and water management (PR/EN) [11][20]. **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 against built (PR/EN) [11][20]

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

- **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) [31]**.** **Weaknesses –** Design implication for colder climates (PR/EG) [32]. **Opportunities –** Utilization of greening for shading (PR/EN) [31][33]. **Threats –** Lack of microclimate understanding (PR); Lack of solar design understanding (PR); No universal best practices method (PR) [31][32][33].
- **Greening (shading): Strengths –** Green shading and evapotranspiration (EN/EG); Wind modification/vegetation control (EN); Alternative and combined options for utilization (PR/EN) [31][33]. **Weaknesses –** Improper placement of greenery trees (PR) [20]. **Opportunities –** Optimizing tree function by proper understanding of tree positioning, structure and anatomy (PR) [31][33]. **Threats –** The lack of understanding of the stated opportunities would be significant threat to ability to use the green function (PR) [31][33].
- **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) [31][33][34]. **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) [31][33][34]. **Opportunities –** Utilization of thermal mass using Phase Change Material (PCM) (PR/H); Proper understanding of PCM in windows, walls and roofs & ceilings (PR/EG) [31][33][34]. **Threats –** Inadequate understanding and planning of load shifting (PR); Heavily dependent performance of the building (EN/EG) [31][33][34][35].
- **Insulation: Strengths –** Limiting thermal Penetration (PR/EG); Reduction of draught (PR/H); Resistant to negative microclimate effects (PR/EN) [31][33]. **Weaknesses –** Improper application of insulation material (PR) [31][33]. **Opportunities –** Proper understanding the material used (PR) [31]. **Threats –** Improper use of the volume and materials for insulation (H) [31][33].
- **Solar Chimney: Strengths –** Utilization 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) [36]. **Weaknesses –**Dependent on the predictability and availability of solar radiation (EG) [31][33][36]. **Opportunities –** Understanding ventilation control (PR); Understanding and maximizing temperature difference (PR); Hotter climactic advantage if applied properly (PR) [36]. **Threats –** Lack of understanding of design control and implementation (PR/EG) [36].
- **Air Vents/Natural Ventilation: Strengths –** Utilization 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); Utilization of curved roof vents (PR); Well established best practices (PR) [31][33][37]. **Weaknesses –** In humid climates, natural ventilation increases indoor humidity (H) [37]. **Opportunities:** Proper understanding of ambient conditions (PR); Proper understanding of design strategy utilization (PR); Location specific implementation of combined natural ventilation strategies such as cross or stack ventilation (PR) [31][33][37].**Threats –** Extreme climactic factors and unpredictability EN, Difficulty in natural ventilation strategy prediction (PR); Complexities in design require specialist understanding (PR) [31][33][37][38].
- **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)[38][39]. **Weaknesses –** Susceptible to dust, other particulate matter and insects (H) [38]. **Opportunities and Threats –** NA
- **Radiative Cooling**

Strengths – Movable insulation (PR/EG); Utilization of Diode roof (PR/EG); Utilization of Roof pond (PR/EG); Paint utilization (PR/EG) [31]. **Weaknesses –** Heavily microclimate dependent (EN) [31]. **Opportunities and Threats –** N/A

- **Evaporative Cooling: Strengths –** Green utilization (PR/EG); Water control and utilization (PR/EN); Material augmentation (PR/EG); Dust control (PR/EN); Utilization of solar heaters (PR/EG) [31]. **Weaknesses –** Lack of efficiency in operation in humid climates but rather best in dry climates (EN) [31]. **Opportunities –** Proper understanding of evaporative functions and options thus more effective utilization (PR/EN) [37][40]. **Threats –** Lack of understanding of evaporative functions especially in hotter climate zones (PR/EN) [37][40].
- **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) [31][33]. **Weaknesses –** Difficult to implement due to the contextual nature, design from climatic and environmental perspective and structural design (PR) [31][33]. **Opportunities –** Regional variations in utilization and application of technique (PR); Proper knowledge of soil and surrounding earth landscape (PR) [31][33]. **Threats –** Proper understanding of design parameters is critical for the benefits of this configuration and is the lack of (PR) [31] [33].

- **Building Envelope: Strengths –** Maximizing advantage of building orientation (PR); Maximizing the use of cross ventilation (PR/EN); Efficient use of construction materials (PR/EG); Reduction and reflectivity of ground surfaces (PR/EG); Maximizing building internal volume and limiting wall barriers (PR) [40][41]. **Weaknesses –** Conflict between natural ventilation and other building requirements such as sound considerations (PR) [40]. **Opportunities –** Orientation and shape of building to avoid direct solar radiation (PR/EG) [40]. **Threats –** Utilization of reflective walls (PR/EG); Optimization of building location orientation and volume (PR) [40].

3. Discussions: Cross Analysis at Three Spatial Levels for Energy-Use Reductions

The comprehensive SWOT analyses above provide an overview of available passive cooling energy systems 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. In this paper, we assess the implications based on our proposed five indicators (i.e. PR, H, EN, EG, & PO).

Macro Level Review - The results in the above lends further understanding to challenges and successes of Passive ventilation systems, 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 is a result 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 utilization 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, however 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 utilization 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.

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, 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 channelization 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 because there are 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 minimization of transport fuel with compactness and utilization 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 be made for its effective use. Hence the consideration of ventilation on the Meso-scale lies in its contextual argument, practice orientation and policy backing.

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 utilization as a passive ventilation technique. 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 don't 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 utilization of any specific passive system but rather it is based on design and practice indicator as well as the energy and environmental prerogative. Unlike meso and macro level which promotes ventilation through wind speed and channelization in both buildings and streets, micro level did not have to contend with both scopes, also 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 a micro level to revolve around micro climate unpredictability and extremes. The advantages and weakness 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 is 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 utilization, 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 on a micro level is largely governed by solar energy.

Three Spatial Levels Overlap - The comprehensive SWOT analyses, which was 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. 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 level, 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. 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.

4. Conclusions

It is well established within this report 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 categorization 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.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. Thus, 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 in developing countries 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.

References

[1] Zhang, A., C. Gao and L. Zhang (2005). "Numerical simulation of the wind field around different building arrangements." Journal of Wind Engineering and Industrial Aerodynamics 93(12): 891-904.

[2] Ng, E. (2009). "Policies and technical guidelines for urban planning of high-density cities – air ventilation assessment (AVA) of Hong Kong." Building and Environment 44(7): 1478-1488.

[3] Hu Ng, E. (2009). Designing High-Density Cities: For Social and Environmental Sustainability, Routledge: 384.

[4] Spirn, A. W. (1986). Air Quality at Street-Level: Strategies for Urban Design. B. R. Authority.

[5] Kastner-Klein, P., E. Fedorovich and M. W. Rotach (2001). "A wind tunnel study of organised and turbulent air motions in urban street canyons." Journal of Wind Engineering and Industrial Aerodynamics 89(9): 849-861.

[6] Johansson, E. (2006). "Influence of urban geometry on outdoor thermal comfort in a hot dry climate: A study in Fez, Morocco." Building and Environment 41(10): 1326-1338.

[7] [Pirjola, L., T. Lähde, J. V. Niemi, A. Kousa, T. Rönkkö, P. Karjalainen, J. Keskinen, A. Frey and R. Hillamo (2012). "Spatial and temporal characterization of traffic emissions in urban microenvironments with a mobile laboratory." Atmospheric Environment 63: 156-167.

[8] Nunez, M. and T. R. Oke (1977). "The Energy Balance of an Urban Canyon." Journal of Applied Meteorology 16(1): 11-19.

[9] Kanakita, R. S., S. K. Singh and M. P.M. (2015). Urban Canyon Modelling: A Need for the Design of Future Indian Cities.

[10] Yamamoto, Y. (2006). Measure to Mitigate Urban Heat Islands.

[11] Doick, K. and T. Hutchings (2013). Air temperature regulation by urban trees and green infrastructure.

[12] Clark, C., B. Busiek and A. Peter. (2010). Quantifying Thermal Impacts of Green Infrastructure: Review and Gaps. Argonne National Laboratory, 955 L'Enfant Plaza SW, Suite 6000 Washington, DC 20024.

[13] Chen, W. Y. (2015). "The role of urban green infrastructure in offsetting carbon emissions in 35 major Chinese cities: A nationwide estimate." Cities 44: 112-120.

[14] Norton, B. A., A. M. Coutts, S. J. Livesley, R. J. Harris, A. M. Hunter and N. S. G. Williams (2015). "Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes." Landscape and Urban Planning 134: 127-138.

[15] Hunter, A. M., N. S. G. Williams, J. P. Rayner, L. Aye, D. Hes and S. J. Livesley (2014). "Quantifying the thermal performance of green façades: A critical review." Ecological Engineering 63: 102-113.

[16] Attia, S. and I. Duchhart (2011). Bioclimatic landscape design in extremely hot and arid climates. Proceedings of 27th Conference of Passive and Low Energy Architecture (PLEA) 2011, Passive and Low Energy Architecture (PLEA).

[17] Ţundrea, H. B., Mihai. (2013). Bioclimate Architecture, A Sensible and Logical Approach Towards the Future of Building Development.

[18] Golany and S. Gideon (1996). Urban Design Morphology and Thermal Performance.

[19] Hough, M. (1995). Cities and Natural Processes. London, England, Routledge.

[20] Ko, Y. (2013). Urban Form and Residential Energy Use: A Review of Design Principles and Research Findings.

[21] Givoni, B. (1998). Climate Considerations in Building and Urban Design. New York, John Wiley.

[22] Khaled, A.-s. (1996). Solar Access/Shading and Building Form: Geometrical Study of the Traditional Housing Cluster in SANA'A

[23] Shashua-Bar, L. and M. E. Hoffman (2003). "Geometry and orientation aspects in passive cooling of canyon streets with trees." Energy and Buildings 35(1): 61-68.

[24] Holden, E. and I. T. Norland (2005). Three Challenges for the Compact City as a Sustainable Urban Form: Household Consumption of Energy and Transport in Eight Residential Areas in the Greater Oslo Region, Routledge.Hough, M. (1995). Cities and Natural Processes. London, England, Routledge.

[25] Jabareen, Y. (2006). Sustainable Urban Form: Their Topologies Models and Concepts. Department of Urban Studies, Massachusetts Institute of Technology.

[26] Nuruzzaman, M. (2015). Urban Heat Island: Causes, Effects and Mitigation Measures - A Review, A Review. International Journal of Environmental Monitoring and Analysis. Vol. 3, No. 2, 2015, pp. 67-73.

[27] Dursun, D. and M. Yavas (2015). Air Quality in the City of Erzurum: Strategies for Climate Sensitive Urban Design. ICUC9 - 9th International Conference on Urban Climate jointly with 12th Symposium on the Urban Environment.

[28] Sailor, D. (2006). Mitigation of urban heat islands - recent progress and future prospects.

[29] Shickman, K. (2014). Cool Policies for Cool Cities: Best Practices for Mitigating Urban Heat Islands in North American Cities. A. C. f. a. E.-E. Economy. Washington, DC.

[30] Akbari, Hashem, M. Pomerantz and T. Haider (2001). Cool Surfaces and Shade Trees to Reduce Energy Use and Improve Air Quality in Urban Areas.

[31] Geetha, N. B. and R. Velraj (2012). Passive Cooling Methods for Energy Efficient Buildings with and without Thermal Energy Storage - A Review, Energy Education Science and Technology Part A: Energy Science and Research. 29(2): 913-946.

[32] Dubois, M.-C. (1997). Solar Shading and Building Energy Use.

[33] Kamal, M. A. (2012). "An Overview of Passive Cooling Techniques in Buildings: Design Concepts and Architectural Interventions." Acta Technica Napocensis: Civil Engineering & Architecture 55, No. 1 (2012).

[34] Osterman, E., V. Butala and U. Stritih (2015). "PCM thermal storage system for 'free' heating and cooling of buildings." Energy and Buildings **106**: 125-133.

[35] Santamouris, M. and P. Wouters (2006). Building Ventilation: The State of the Art. UK, Earth Scan.

[36] Dimoudi, A. (2009). "Solar Chimneys in Buildings—The State of the Art." Advances in Building Energy Research **3**(1): 21-44.

[37] Aynsley, R. (2007). Natural Ventilation in Passive Design.

[38] Dehghani-sanij, A. R., M. Soltani and K. Raahemifar (2015). "A new design of wind tower for passive ventilation in buildings to reduce energy consumption in windy regions." Renewable and Sustainable Energy Reviews **42**: 182-195.

[39] Hughes, B., K. J. Caulautit and S. Shazhard (2009). Adapting Buildings to meet the Energy Challenge.

[40] Okba, E. M. (2005). Building envelope design as a passive cooling technique. International Conference of Passive and Low Energy Cooling for the Built Environment. Greece.

[41] Sadineni, S. B., S. Madala and R. F. Boehm (2011). "Passive building energy savings: A review of building envelope components." Renewable and Sustainable Energy Reviews **15**(8): 3617-3631.

Biography: Dr Ali Cheshmehzangi has qualifications, practice experience and a research profile in urban design, sustainable urban planning and development. He is also a founder member and director of International Network for Urban and Rural Research (INURR) in China.