



Shelter Initiative for Climate Change Mitigation and Adaption (SICCMA)

Scoping Paper

***Sustainable Building Practices for Low Cost Housing:
Implications for Climate Change Mitigation and
Adaptation in Developing Countries***

February 2011

Executive Summary

Energy use in housing is a key contributor to climate change, with housing accounting for approximately 40 per cent of greenhouse gas emissions worldwide. This paper explores the ways in which technological improvements in building materials and design can be married with indigenous knowledge in developing countries to fulfill the objective of greater provision of low cost sustainable housing that is both climate adaptive and has low greenhouse gas emissions. Low cost sustainable housing is defined as housing that is affordable to the population that it serves, with minimal environmental impact, and that is durable and permanent.

Key findings of the paper are:

- There is considerable scope to improve the coordination of low cost sustainable housing provision across developing countries;
- Effort should concentrate on modifying and tailoring developed country housing standards, guidelines, design tools and life cycle assessment tools so they are suitable for developing countries – they cannot be adopted without modification;
- Development of standardized regional housing guidelines will encourage and improve upon the provision of low cost sustainable housing – these guidelines should integrate local knowledge and building materials, as well as bioclimatic design principles;
- The Clean Development Mechanism ('CDM', under the UN FCCC Kyoto Protocol) has thus far been ineffective at encouraging the development of low cost sustainable housing. However, the central role of housing in climate mitigation and adaptation is increasingly recognised within the UN FCCC and future reforms to the CDM look set to encourage precisely these types of housing projects.

Low cost sustainable housing policies, standards, and techniques have the potential to provide multiple benefits for residents and the wider population, including: reduced greenhouse gas emissions, durability and resilience to climate change, health benefits, and poverty alleviation. Efforts to encourage the provision of sustainable low cost housing must be sensitive to local and regional variations in climate, governance structures, building and design expertise, and local materials.

Increasingly housing provision should also be sensitive to predicted regional changes in climate and extreme weather events (flooding, heat-waves, drought etc). Developing countries are particularly vulnerable in this regard. It is vital that new housing is built to take account of climate change, as these dwellings have a typical design life of 20-50 years.

The report provides discussion and analysis of a range of issues judged to be most pertinent to the objective of encouraging sustainable building practices for low cost housing in developing countries, including:

- a review of international and national building energy codes, standards and voluntary guidelines (Section 3.2);
- an assessment of techniques to evaluate the impact of housing on climate change (life cycle analysis, energy modeling, etc.) (Section 3.3);
- a review of policies and financial mechanisms which support or have the potential to support the provision of low cost sustainable housing (e.g. under the UNFCCC, foreign aid) (Sections 3.4 and 3.5);
- identification and analysis of locally-appropriate building materials and techniques that address the twin goal of climate mitigation and adaptation (e.g. passive solar heating, natural ventilation) (Chapter 4);
- an assessment of the importance of regionally appropriate design and building, with integrated stakeholder involvement (Section 4.3).

The key recommendations for action by housing sector stakeholders are:

- Develop partnerships with existing LCA/LCI key players to develop LCI data in regions where it does not exist.
- Develop initiatives with CDM developers, UNEP, SBCI, Designated Operational Entities and the CDM Executive Board to develop and gain approval of new methodologies that improve access to carbon financing for low cost sustainable housing projects.
- Improve integration of climate mitigation and adaptation aspects of low cost sustainable housing – at the level of building regulations (on the ground) and at an institutional level
- Develop partnerships with international aid organisations to develop stakeholder centric low cost sustainable housing initiatives.

- Work with international trade organisations to improve access in developing regions to standardised energy efficient building and household products.
- Promote educational programmes in developing countries to increase knowledge on sustainable building practices and LCA thinking.
- Develop a comprehensive review of disaster resistant and low cost-sustainable building techniques and materials, focussing on indigenous methods (such as cyclone resistant housing traditions in the Asia-Pacific region).
- Produce a detailed review of existing relevant building energy codes, guidelines and standards to assess which can serve housing sector stakeholders in developing comprehensive policies to promote climate change mitigation in low cost sustainable housing in regionally appropriate designs.
- Produce a detailed review of existing building energy modelling software tools which can be utilised in specified developing regions to quantify energy conservation achievements within regionally appropriate housing designs
- Produce a detailed review of existing LCA tools and LCI databases which can be utilised in developing regions to quantify the embodied energy of specific building materials and home designs.
- Develop easily accessible prototype plans by region which comprehensively address local stakeholder preferences, energy conservation, climate adaptive capacity and social benefits.

Table of Contents

Executive Summary	pg. 2
List of Abbreviations and Acronyms	pg. 7
1. Introduction	pg. 8
1.1. Objectives of the study	pg. 8
1.2. Defining the problem and the solutions	pg. 9
1.3. Summary of key findings of this Scoping Paper	pg. 10
2. Definitions	pg. 14
3. Policies, Initiatives and Tools: Benefits and Applicability for Developing Nations	pg. 15
3.1. Overview of Regional Trends	pg. 15
3.2. Building Energy Codes, Standards and Voluntary Guidelines	pg. 16
3.3. Measuring the Effects of Housing on Climate Change	pg. 24
3.3.1. <i>Building Energy Modelling</i>	pg. 24
3.3.2. <i>Quantifying the Carbon Footprint of Building Materials and Construction with life Cycle Assessment</i>	pg. 28
3.4. The Clean Development Mechanism and the Built Environment	pg. 33
3.5. Foreign Aid and International Cooperation on Low Cost Sustainable Housing	pg. 38
3.6. Overview of Key Issues for Developing Nations: Gaps and Challenges	pg. 43
4. Appropriate Building Materials and Techniques	pg. 46
4.1. Best Practices for Climate Change Mitigation	pg. 46
4.1.1. Regionally Appropriate Energy Efficient Design	pg. 46
4.1.2. Low Cost and Local Low Embodied Energy Materials	pg. 54
4.1.3. On-Site Renewable Energy Technologies	pg. 59
4.2. Best Practices for Climate Change Adaptation	pg. 61
4.2.1. Overview of Regional Vulnerabilities and Adaptation Capacity	pg. 61
4.2.2. Durability and Resilience Planning	pg. 64
4.2.3. Water Security Through Rain Catchment and Re-use	pg. 66
4.2.4. Food Security and Urban Agriculture	pg. 71
4.3. The importance of Regionally Appropriate Design	pg. 73
4.3.1. The Benefits of Standardized Guidelines and Prototype Plans by Region	pg. 76
4.3.2. The Role of Local Indigenous Knowledge and Self-Help Methods	pg. 78
4.4. The importance of WIN-WIN-WIN Synergies	pg. 79
4.4.1. Principles and Examples for Climate Change Mitigation and Adaptation (WIN-WIN's)	pg. 80
4.4.2. Implications for Employment of Low Skilled,	

Under-Educated Labour for the Alleviation of Poverty (3 rd WIN)	pg. 81
4.4.3. Integrated Urban Sustainability Planning	pg. 82
5. Conclusions	pg. 85
5.1. Summary of Key Findings	pg. 85
5.2. Recommendations for Action-Research	pg. 88
6. References	pg. 90

Acknowledgements:

The draft of this Scoping Paper was prepared by Mark Giorgetti, with assistance from Dr. Heather Lovell, Leslie Gallatin, Jeremiah Kidd, Alfred von Bachmayr.

List of Abbreviations and Acronyms

4AR:	Forth Assessment Report of the IPCC
ASHRAE:	American Society of Heating Refrigeration and Air-conditioning Engineers
BREEAM:	Building Research E Environmental Assessment Method
CDM:	Clean Development Mechanism
CMP:	Conference of the Parties acting as the Meeting of the Parties to the Kyoto Protocol
COP:	Conference of the Parties to the UNFCCC
DOE's:	Designated Operational Entities
DOE:	US Department of Energy
EGM:	Expert Group Meeting
FGEF:	French Global Environment Facility
GEF:	Global Environment Facility
ICE:	The University of Bath's Inventory of Carbon and Energy
IDDRI:	Institut du Developpment Durable et des Relations Internationales
IEA:	International Energy Agency
IECC:	International Energy Conservation Code
IPCC:	Intergovernmental Panel on Climate Change
ISO:	International Standards Organisation
LCA:	Life Cycle Assessment
LCI:	Life Cycle Inventory
LEED:	Leadership in Energy and Environmental Design
NGO:	Non-Governmental Organisation
NREL:	National Renewable Energy Laboratory
PV:	Photovoltaic
SBCI:	Sustainable Building and Construction Initiative
SERT:	University of Bath's Sustainable Energy Research Team
SETAC:	Society for Environmental Toxicology and Chemistry)
UNCHS:	United Nations Centre for Human Settlements
UNDP:	United Nations Development Programme
UNECE:	United Nations Economic Commission for Europe
UNEP:	United Nations Environment Programme
UNFCCC:	United Nations Framework Convention on Climate Change
UNISDR:	United Nations International Strategy for Disaster Reduction
USGBC:	US Green Building Council
ZEH:	Zero Energy Home(s)

1. Introduction

The convergence of climate change, increasing global population, rapid urbanisation and the need for poverty alleviation in developing nations sets the stage for this Scoping Paper. In the realm of climate change mitigation, no sector is more able to produce cost effective reductions in energy consumption and greenhouse gas emissions than the building sector (Levine et al., 2007; Urge-Vorsatz & Novikova, 2008). In the realm of population and urbanisation, housing remains a key facet of sustainability and poverty alleviation. Rapid growth in developing nations heralds the necessity for appropriate sustainable housing policy and practices which synergistically address issues of poverty, sustainability, climate change mitigation and adaption.

1.1 Objectives of the Scoping Paper

This Scoping Paper assesses and explores the important and inter-related issues of providing low cost sustainable housing in developing nations whilst simultaneously addressing climate change mitigation and adaptation. The term sustainable in this context encompasses a complex web of issues including environmental protection, improvements in quality of life, poverty alleviation and is looked at through the perspective of long term, life cycle sustainability that is integrated with indigenous local customs and cultures to provide lasting and replicable improvements to the lives of local populations.

The study explores the ways in which indigenous knowledge, traditional methods, and low embodied energy local building materials can be integrated with state of the art building science and advanced design tools to improve low cost energy efficient sustainable housing in developing nations.

The Scoping Paper overviews existing knowledge, lead research, best practices, key partners and academic institutions in the field of low cost sustainable housing and sustainable land use for housing and concludes with recommendations for action-research.

1.2 Defining the Problem and the Solutions

Buildings and housing account for roughly 40 per cent of all energy consumption and greenhouse gas emissions around the world. The specific percentage varies slightly from nation to nation, but it is interesting to note that amongst both developed and developing nations it is generally consistent that roughly 40% of a nation's total energy consumption occurs within buildings. For instance, in Indonesia about 40% of total energy consumption and associated greenhouse gas emissions are due to energy consumption in residential buildings which is roughly the same percentage in highly developed nations such as the United States at 35% total energy consumption from buildings (Utama & Gheewala, 2009). Although total energy consumption and greenhouse gas emissions vary dramatically between developed and developing nations (with developed nations generally contributing far more to global emissions and energy consumption than developing nations) it is important to note that building sector energy related emissions remain a substantial contributor in virtually every nation. And housing in developing nations is an important aspect to this.

Energy consumption within homes and the associated environmental and economic costs attributable to this is a significant global issue. In developing nations the rate of growth in the construction and housing industries is rapidly increasing and for emerging nations, exceeds that of developed nations. Expected growth rates in China foretell the addition of newly constructed buildings equal in total floor space to the entirety of the current US building sector. This is expected to be accomplished as rapidly as by the end of the next decade. China is expected to produce 1 billion square meters of new construction annually for the next 15 years (FGEF, 2003). At this magnitude, if new buildings in emerging economies fail to be the most energy efficient and sustainable as possible, the globe faces a multi-decade lock-in of dangerous energy consumption patterning which will likely aggravate economic and environmental challenges. The importance of developing useful and accessible tools for the successful design and construction of sustainable, energy efficient housing in developing nations is paramount in both the struggle to end poverty and in meeting the growing challenges of climate change.

Poverty alleviation and improvements to health, safety, sanitation and adequate shelter within the least developed nations and urban slums amongst all developing nations can be addressed in part through sustainable low cost housing initiatives.

There are important and attainable 'WIN-WIN-WIN' strategies which are being deployed in developed and developing nations to address the myriad sustainability issues within housing. 'WIN-WIN-WIN' strategies can be described as those that provide benefits for reducing greenhouse gas emissions across the economy attributable to buildings across their life cycle; while at the same time providing climate adaptive capacity through durability and resilience to changing climatic conditions such as flooding, extreme storms and extreme heat; and at the same time providing social benefits in the form of improved quality of life, poverty alleviation and improved health and safety.

The key principle is that low cost sustainable housing policies and methods must aim to provide multiple benefits across multiple aspects in a way which supports the improvement of people's lives, their livelihoods and the greater environment.

The issues and methods explored in this Scoping Paper aim to highlight ways in which this integrated mind set can be increased and fostered by the work of UN-HABITAT and its partners, especially where state of the art advances in housing design and construction can be coupled with traditional locally appropriate methods and materials.

1.3 Summary of Key Findings of this Scoping Paper

- Low cost sustainable housing is being implemented in developing countries to improve quality of life, reduce greenhouse gas emissions and provide protection from adverse climate change impacts, but capacity to coordinate and advance these efforts are limited or inconsistent.
- Advanced standards, guidelines, design tools and life cycle assessment tools, which are available in developed nations can be utilised to a limited degree in developing nations. International efforts should be increased to adapt existing tools, standards and guidelines for increased availability and usefulness in developing nations, especially for developing building energy codes and databases of embodied energy in building materials.

- International efforts to increase and improve low cost sustainable housing for developing nations have demonstrated some success, especially when local stakeholders are integrated into the process early and through completion.
- The Clean Development Mechanism (CDM) under the Kyoto Protocol has been, thus far, ineffective at supporting low cost sustainable housing in developing nations. There is however, growing awareness of this shortcoming of the CDM, and efforts are increasing to provide improved access to carbon financing for building sector projects. Significant reformation of the CDM and innovation amongst CDM developers is needed to make carbon financing a viable mechanism for housing projects. Access to the CDM requires quantifiable and verifiable reductions in emissions which are additional to business as usual activities. It is often technically or economically infeasible to demonstrate this for small scale housing projects.
- In order to mitigate climate change by reducing energy consumption and greenhouse gas emissions attributable to housing, regionally appropriate housing design which optimises bio-climatic design principles is needed. This can be enhanced through the use of advanced energy modelling software.
- It is important to understand that in most cases, the life cycle climate impact of a home is predominantly in the energy consumption required to heat, light and cool the building. The embodied energy of the building materials generally has a lesser climate impact over the life cycle of the dwelling.
- There are numerous proven techniques that are passive or low energy, low tech and affordable to maintain comfort within a dwelling while minimising energy consumption. These include: passive solar heating, thermal mass, natural ventilation, evaporative cooling, other passive cooling techniques, high performance building envelopes and energy efficient mechanical systems. All of the above should be optimised in a housing design based on climatic data and human comfort expectations.

- The use of low cost, local and low embodied energy materials are an important aspect of sustainable construction, and can improve the environmental life cycle assessment of a dwelling, while supporting local economic development, self help indigenous methods and reducing environmental impacts.
- On-site renewable energy technologies can reduce greenhouse gas emissions, improve access to basic energy needs, such as lighting or hot water, and increase adaptive capacity. Costs and limited technological knowledge can limit the effectiveness of these technologies for the least advantaged. Renewable energy remains a critical component for sustainable housing in terms of climate change mitigation and adaptation.
- Housing design which integrates durability and resilience planning according to the expected climate impacts specific to the region and building site, can serve to increase adaptive capacity and reduce damage risks from climate change. Indigenous methods can serve as examples of climate resilient, low cost and sustainable housing options.
- Water and food scarcity is expected increase in many regions due to climate change. Sustainable housing design which utilises rain water catchment, waste-water (greywater) re-use and intelligent landscaping for water conservation and household gardening can serve to reduce the climate risks and improve adaptive capacity at low cost.
- Sustainable housing design with integrated living structures can also serve to increase energy efficiency and adaptive capacity by increasing passive cooling opportunities, access to biomass based fuels and protection from winds and extreme weather. Examples are vegetative roofs, vegetative wind breaks and climbing vines on trellises to shade buildings.
- Regionally appropriate housing design which integrates and optimises synergistic (WIN-WIN-WIN) opportunities to address climate change and improve the human condition should be carefully crafted in ways which are

appropriate to the location and the occupants, while encouraging indigenous stakeholder input and ownership as a core design principle. These designs must also be integrated with sustainable urban planning to optimise access to employment, social activities, transportation and recreation.

- Standardised guidelines by region will be very useful to the replication and advancement of efforts to improve low cost sustainable housing and access to it. Local indigenous know-how and state of the art design optimisation tools should be jointly employed to develop proto-type plans and model homes that are attractive to and can be easily replicated by the local population. Prototype plans must be technically simple and accessible to illiterate peoples, be optimized according to regional climatic conditions utilizing passive, low energy design characteristics, be influenced by advanced energy efficiency standards, codes and guidelines from regions or nations with well established research and implementation experience, and utilize state of the art energy modelling and life cycle assessment tools to provide quantifiable and measurable results which can be verified in the field.

2. Definitions

Low Cost Sustainable Housing: It is important to be clear that low cost is a relative concept and what may be considered low cost in one population will not necessarily be low cost in another. For the purposes of this study, low cost housing will refer to housing which is reasonably affordable to the population that it will serve. It is not synonymous with 'social' or low income housing. And, generally speaking, the sustainable aspect of this term refers to housing which minimises environmental impacts and is durable and permanent. For the purposes of this study, it does not refer to emergency or temporary housing, unless specifically mentioned.

Climate Change Mitigation: In the context of this study this term refers to efforts to limit or reduce anthropogenic forcing of climate change, generally in terms of greenhouse gas emissions reductions through energy conservation, efficiency and reduced life cycle emissions including embodied energy of materials and/or construction techniques

Climate Change Adaptation: in the context of this study this term refers to the efforts of housing design to limit the damages and/or risks associated with existing or increased climate change stresses. Adaptation efforts will be necessarily regionally specific based on climate stresses expected by region with current and future climate change.

Embodied Energy: Refers to the life cycle energy inputs attributable to a given product or assembly of products.

Indigenous: In the context of this study this term refers to the people, natural resources or geographical characteristics of a given place. It also refers to the traditional native population of a place and their associated customs, knowledge and lifestyle.

3. Policies, Initiatives and Tools: Benefits and Applicability for Developing Nations

3.1 Overview of Regional Trends

Most successful building policies, initiatives and tools to address and measure the climate impacts of housing have to date been developed and are being used primarily within developed nations. These include:

- Building energy codes, standards and voluntary guidelines for residential construction,
- Software-based building energy modelling software to optimize energy performance in design.
- Life cycle assessment tools to measure embodied energy of building materials and overall life cycle environmental performance of housing,

Some of these are applicable or potentially applicable for use in developing nations, and indeed are already in use in some cases. China has been developing building energy codes since the 1980's (Lee & Chen, 2008). This sets China ahead of most developing nations who have either just begun to recognise the need for such regulation or have not advanced at all on this front. Other medium and high income developing nations are aiming to or beginning to address housing energy efficiency and sustainability within their policy frameworks, but to date these initiatives have not been well-assessed, especially in the academic literature (for notable exceptions see Fayaz & Kari, 2009). Lesser developed nations, especially in Africa, have made little, if any, progress on instituting appropriate sustainable housing or energy efficiency policies for buildings

The ever increasing trend of urbanization for developing nations, especially in Asia, brings important issues to bear on efforts to address low cost sustainable housing. Within recent years the number of human beings dwelling in urban areas has surpassed those dwelling in rural areas. This is the first time in human history that this has been the case. It is expected that this trend will accelerate, bringing a full 2/3 of the global population within urban dwellings by the year 2050 (UN-HABITAT, 2008). So any efforts to foster low cost sustainable housing must focus on the

growing trends toward urbanization, while maintaining adequate focus on rural housing policies as well.

On an international level, the United Nations Framework Convention on Climate Change (UNFCCC) and the parties to the Kyoto Protocol are in the process of reforming the Clean Development Mechanism (CDM). Growing attention is focused on reforming the methodologies and mechanisms of the CDM to foster greater participation amongst sustainable building projects in developing nations, especially in Africa, Asia and Latin America. Currently CDM offers very little to the efforts of low cost sustainable housing, but emerging reform agendas supported by recent academic studies show promise that this tool may become more significant in the building sector in coming years (Cheng et al., 2008; Li, 2009).

The Global Environmental Facility (GEF) and other aid organizations are demonstrating important successes in bringing advanced technology and expertise to sustainable housing efforts in China, Afghanistan, Pakistan and some areas in Latin America.

Although some efforts have been effective, there remain significant gaps and challenges to achieving low cost sustainable housing in the developing world, and these will be discussed in each of the following sections and summarized in Section 3.7. This chapter reviews some of the key areas of interest for improving sustainable housing development by assessing in turn: current codes, standards and guidelines; tools for measuring the climate impacts of housing; the current state and proposed changes to the CDM; and examples of successful foreign aid initiatives around the world.

3.2 Building Energy Codes, Standards and Voluntary Guidelines

Today there are many energy building codes, efficiency standards and voluntary guidelines for reducing energy consumption and environmental impacts associated with buildings and homes. Within the academic literature it is well known that building codes, efficiency standards and voluntary methods have been shown to be very effective, at a low cost to society, in mitigating the effects of the building sector on climate change (Levine et al., 2007; Urge-Vorsatz & Novikova 2008). As well,

lighting, appliance and building efficiency standards are identified as amongst the lowest cost greenhouse gas abatement options available (McKinsey, 2007).

By definition codes and standards are minimum requirements, and seldom offer any incentive for innovation or attainment beyond the minimum. But when coupled with voluntary methods and proper incentives, these tools can stimulate important shifts towards greater sustainability and reduced greenhouse gas emissions from the building sector and housing (Bertoldi et al., 2005). It is important to make the clear distinction between building energy codes or efficiency standards which are mandated by law and those which are voluntary. Because the extent of mandatory building regulations (and especially those relating to energy or sustainability) are, for the most part, nascent or non-existent within the policy frameworks of most developing countries, we do not seek to separate voluntary and mandatory methods explicitly in the discussion, but to review the benefits and applicability of either in the context of improving climate change mitigation and adaptation through housing.

Here we seek to review current trends within selected developing nations, especially the recently emerging economies, and to highlight some important codes, standards and voluntary guidelines which can serve to inform policy efforts of UN-HABITAT, and to identify ways in which existing methods can be applied in the field, regardless of an established code system. It is notable that current building codes do not, as a general rule, offer separate guidance for low cost homes although at least one voluntary guideline in the US is working to overcome this and is discussed below. Arguably there are specific issues for low cost homes with respect to sustainability, especially if their construction is government-funded. There is a strong case for governments taking a lead in setting high standards for sustainable homes. We consider separately mandatory and voluntary codes.

The 1980 UNCHS (Habitat) paper entitled, *Building Codes and Regulations*, discusses the lack of building codes for developing nations as of 1980, and in many respects it appears that very little has changed in this regard, with the important exception of China and a few other emerging economies.

China is the global leader of the development and use of building energy codes amongst developing and emerging nations. In recent years China has created numerous national codes to address sustainability and energy conservation in the building and housing sectors. These include are listed in Table 3.2 below.

Chinese Building	
Energy Codes	Name
GB/T 50378-2006	An Evaluation Standard for Green Building
GB 50352-2005	The Code for the Design of Civil Buildings
GB50189-2005	A Design standard for Energy Efficient Public Buildings

Table 3.2a: Some Chinese Building Energy Codes (www.codeofchina.com)

Although these codes are specific for large commercial buildings they demonstrate an awareness and progress towards institutionalising building energy efficiency and sustainability. The Code for the Design of Civil Buildings (GB 50352-2005) explicitly requires buildings to reduce pollution, environmental impacts, energy and resource conservation and be designed for disaster resilience. Code GB50189-200, A Design Standard for Energy Efficient Public Buildings, requires buildings to reduce energy consumption by at least 50% from previous standards. Building upon the policy efforts in the commercial building sector, China has initiated a number of residential energy efficiency codes that are specified according to climatic zones for optimum effectiveness. These residential energy codes are designated by the prefix JGJ, and are too numerous to list here, but can be accessed at www.codeofchina.com.

The Chinese building energy and green building codes have been demonstrated to be relatively effective as compared to other building energy codes in Asia, especially as compared to those in Hong Kong (Lee & Chen, 2008). But there remain significant shortcomings in the enforcement and proper implementation in the field (Li, 2009). Additionally, investment decision making remains firmly rooted in short term economic gains not in long term savings in energy costs (Li, 2009). So although the creation of comprehensive building energy codes in China is important and can influence other Asian countries, there remains need for improvement.

The Chinese Ministry of Construction seems aware of this issue and has initiated an effort on reinforcing building energy efficiency with the intention of reforming the building industry around efficiency and sustainability (Liang et al., 2007).

In India, the need for such standards has only recently come onto the agendas of Indian government agencies. As of 2007, the very first energy code for buildings was created in India. It addresses only large commercial buildings, and not housing.

This code is inspired by building energy codes and standards developed in the United States including the ASHRAE (American Society of Heating, Refrigeration and Air-conditioning Engineers) codes and guidelines and the California building energy code (IEA, 2008); thereby demonstrating how standards created for use in developed nations can serve to assist developing nations in their efforts.

Other emerging economies have varying levels of building energy codes and enforcement strategies. These include Iran, Turkey, Pakistan, Brazil, Tunisia, Mexico and Costa Rica.

The 1980 UNCHS (Habitat) paper entitled *Building Codes and Regulations in Developing Countries* demonstrates several important points regarding the needs for advancement of codes and proposed methods for advancing the adoption of codes within developing nations. Especially pertinent points for this study include:

- Codes should serve to enhance the capabilities of the local population to build for themselves.
- Codes should reflect the specific needs of the demographic they hope to serve, and therefore should be regionally specific.
- Building codes should be adopted in a stepped approach, serving the greatest number of the least advantaged first, and improving overall building safety and performance over time, as larger numbers of the least advantaged gain improvements in their living and working situations.
- Infrastructure to provide clean water and sanitation must take precedence over other code goals.
- Education and training of the local workforce, self-help participants and government code officials is extremely important to success.
- Enforcement should focus on incentives over punishment, as code adoption is in its early stages.

One of the most important recommendations from the 1980 UNCHS report for this study is that prototype building plans should be developed for low income groups, with full scale model homes as examples that can be easily implemented by the local population.

This Scoping Paper, further recommends that any such prototype plans must be technically simple and accessible to illiterate peoples, be optimized according to

regional climatic conditions utilizing passive, low energy design characteristics, be influenced by advanced energy efficiency standards, codes and guidelines from regions or nations with well established research and implementation experience, and utilize state of the art energy modelling and life cycle assessment tools to provide quantifiable and measurable results which can be verified in the field. This last point will be particularly important to UN-HABITAT efforts to access carbon financing through the Clean Development Mechanism under the Kyoto protocol. All of these issues are returned to in the following sections.

As discussed, there is potential for developing countries to adopt (with modification) existing standards and building codes already in use in developed countries. For this reason we briefly review some examples of such codes, from the Swiss International Standards Organization (ISO) and the United States. We highlight features which may serve to be a very good basis for use in the development of prototype homes and home plans, as well as in the further advancement of building codes for developing nations.

ISO, in recent years, has put forth several new standards aimed at establishing frameworks for determining sustainability indicators in the built environment. These are detailed in table 3.2b below.

ISO Standard	Description
ISO 21930:2007	Standard for the declaration of environmental performance of building materials
ISO 15392:2008	Life cycle assessment of building materials
ISO 14064 and ISO 14065	Quantifying greenhouse gas emissions
ISO 14040:2006	Standard approach to life cycle assessment
ISO 21929:2007 and ISO 21931: 2006	Methods for the determining the environmental performance of buildings

Table 3.2b: ISO standards of interest to sustainable housing (www.iso.org)

Of these ISO 21930:2007 and ISO 15392:2008 should be of interest to efforts in attaining quantifiable results in sustainable housing for developing countries. ISO 21930:2007 is a standard methodology for the declaration of environmental performance of building materials, which can be used to establish the embodied

energy/carbon of building materials. ISO 15392:2008 sets the basis for a suite of new standards addressing sustainability in the built environment, including Life Cycle Assessment (LCA) of building materials. Specifically interesting to efforts in developing countries is this standard's provisions to account for regionally specific criteria including social parameters, health issues, and comfort, regional energy mix, alongside environmental impacts. Amongst the social criteria it can accommodate are issues of poverty alleviation, religion, and job creation. These criteria are potentially very useful for the assessment of building material and design options for efforts to establish sustainable low cost housing in developing nations. Other ISO standards which may be of relevance include: ISO 14064 and ISO 14065 in addressing carbon emissions quantifications; ISO 14040:2006 for the standardized approach to LCA work; and ISO 21929:2007 and ISO 21931: 2006 for methods of environmental performance in buildings.

In the US, four important examples of housing energy codes and voluntary guidelines exist which could be of use to developing nations: first, the IECC (International Energy Conservation Code) developed by the International Code Council; second ASHRAE; third, the ongoing development and market expansion of the LEED (Leadership in Energy and Environmental Design) voluntary assessment tool for buildings and homes created by the US Green Building Council (USGBC); and fourth the ENERGY STAR program developed by the US Department of Energy.

Voluntary guidelines are important in encouraging examples of best practice, and also give an indication to those in the housing construction industry about the likely direction of mandatory codes.

The IECC is a set of code requirements which have been adopted by many local and state governments in the US to assure improved energy performance and comfort for homes and buildings. The basic guidelines set out by the IECC are tailored to North American climate zones and common building methods, but can serve as guidelines for the development of energy efficient housing in developing nations. In particular, the IECC guidance on limiting air infiltration, executing insulation installation properly and to the greatest affect and its guidelines on lighting efficiency are relevant to any climate zone or building style. The IECC specific requirements for different climate zones are a valuable approach which should always be considered in code creation or housing design. A full review of the IECC can serve

to better inform housing sector stakeholders as they embark on design projects for energy efficient low cost sustainable housing around the world (for key reading see [www.iccsafe.org/Store/Pages/Category.aspx?cat=ICCSafe&category=7130&parentcategory=Store Products,330&parentcategory=2410](http://www.iccsafe.org/Store/Pages/Category.aspx?cat=ICCSafe&category=7130&parentcategory=Store%20Products,330&parentcategory=2410)).

ASHRAE offers a set of codes and guidelines which are intended for commercial buildings and residential buildings larger than three floors in height. ASHRAE has formed the basis of other building energy codes and guidelines such as the 2007 building energy code in India and the LEED building assessment tool.

The LEED system has been in existence since the 1990's in the US, but it was not until 2007 that the USGBC established the *LEED for Homes* program which addresses a multitude of energy and sustainability criteria specific to single and multi-family homes under 3 floors in height. The LEED for Homes system is not a building code, but a voluntary credential which serves to advance achievement beyond the minimum standard, and it differs in many respects from the original LEED rating system which was designed for commercial projects. At LEED's core is the encouragement of an integrated design team approach, where all stakeholders in the construction and design process meet at regular intervals to discuss planning, optimization and troubleshooting to assure a higher rate of success in the project achieving its goals. LEED for Homes addresses a myriad of sustainability issues for housing and as such it provides a valuable model for development of sustainable low cost housing in developing countries. LEED for Homes criteria include sustainable sites [preserving the natural integrity of the building site and avoiding damage to prime agricultural land, public open space or habitat for endangered species], location and linkages [encouraging access to mass transit and sustainable urbanization over sprawl], water efficiency, energy efficiency, indoor air quality, sustainable materials [including local, low embodied energy materials, recycled or re-used materials and sustainably harvested raw materials], waste management and recycling, durability planning [designing homes and the materials within them to be resistant and resilient to local natural risk factors, such as flood, storm, intense UV, pests and other issues] plus education and awareness for the public and the occupants alike (USGBC, 2008). Generally LEED for Homes projects must meet rigorous third party verification in order to achieve certification, this process can add

small upfront costs and time to a building project, and may add unnecessary complications to work within developing nations.

As well, LEED for Homes and similar voluntary guidelines do not expressly address or support low cost housing, and in some cases can increase the cost of housing, if only marginally. But in the US, a new voluntary criteria has recently emerged which is based very closely on the LEED system. The Green Communities Criteria is a set of sustainability criteria which mirror the LEED system, but are expressly tailored to low cost, or “affordable” housing projects in the US. The Green Communities Criteria is recognised by many state governments and the federal government for the purposes of qualifying for important tax incentives which have greatly increased the successful completion of green affordable housing in the United States. This model of using LEED inspired criteria, tailored to low cost housing to qualify a project for government financing is a model which may be useful to the efforts of UN-HABITAT.

The guidelines and criteria set out in the LEED system could be explored and adapted to the fullest extent appropriate in UN-HABITAT projects as it offers a comprehensive and achievable set of sustainability guidelines which are relevant in any building project. However, to date there are no known case studies of the LEED for Homes method being used within developing countries. There are a handful of cases of the LEED system being used on commercial building projects in India. At least one developer, Wipro, has been acknowledged with an award from UN-HABITAT for their accomplishments in this regard. And USGBC is supporting a global effort to improve access to LEED by supporting country specific Green Building Councils through the World Green Building Council (www.worldgbc.org) and national Green Building Councils in developing nations. . The World Building Council posts a global directory of national Green Building Councils around the world at <http://www.worldgbc.org/green-building-councils/gbc-directory>. Current participants include India, Brazil, Mexico and others. The Indian Green Building Council, for one, is currently promoting the LEED for Homes programme, but it is unknown if any completed LEED projects exist for low cost sustainable housing .Especially important in terms of climate change adaption is the LEED for Homes approach to durability planning, which requires builder’s and designers to assess the full range of possible natural and climatic risk factors which may serve to harm a building and implement strategies in the field to minimize those risks. These often

refer to issues of material choice and resilient design so as to avoid damage to the home during extreme events. This durability planning mindset could be interpreted, adapted and improved to any local environment or building type.

A fourth standard, the DOE ENERGY STAR program is important in many ways, as it sets of numerous standards for energy efficiency in appliances, electronics and lighting. As well the ENERGY STAR Homes program sets out important energy efficiency guidelines compatible with the IECC and LEED guidelines. In particular the ENERGY STAR *Thermal Bypass Checklist* is a user friendly set of criteria to be applied in the field which serve to assure improved energy performance of the thermal envelope of a home or building. Further reading on the ENERGY STAR Homes program and the *Thermal Bypass Checklist* is available at http://www.energystar.gov/index.cfm?c=new_homes.hm_index

There are numerous examples of advanced energy building codes, standards and guidelines around the world including others that are not discussed here, such as BREEAM (Building Research Establishment Environmental Assessment Method), a UK based building assessment tool similar to LEED, the European Union's Energy Labelling Scheme and others. These and the examples discussed above offer insight and scientifically appropriate criteria to attaining advanced energy efficiency and increased sustainability measures within housing construction. A full detailed review of the applicable codes and guidelines in existence can serve UN-HABITAT in maximizing its sustainability and climate change mitigation goals for low cost housing.

3.3 Measuring the Effects of Housing on Climate Change

3.3.1 Building Energy Modelling

The use of software based building energy modelling software is a growing trend around the world, with many cities within developed nations now requiring it for new construction permits, and more and more architects, engineers and developers are relying on software to make important decisions about energy efficiency and building design. Use of these software tools can provide improved design in housing based on climatic data, which reduces energy demand while improving comfort and indoor environmental quality (through optimized ventilation). As well, energy modelling is

now being used to maximise energy efficiency and conservation in home design, especially in Europe and the US. It is important to understand that energy modelling is not an exact science, as there are numerous variables to contend with in building construction and weather and climate data.

As with all calculations, and software tools, the most important thing is to have correct and appropriate input data. And different building energy modelling tools will rely on different sets of inputs, making some more appropriate in certain applications than others. Generally these tools ask of the user the following: data inputs related to climatic zone, building geometry, orientation, sizing and thermal performance of windows and doors, building envelope construction and thermal properties, occupancy, lighting specifications, and heating, ventilation and air conditioning (HVAC) design and efficiency specifications. Some tools are better suited to residential homes, others more for commercial or large multi-family dwelling buildings, still others can be utilized in both applications.

Energy modelling is being used with current building knowledge and technology to produce numerous homes in developed countries which are “Zero Energy” or near zero energy. A Zero Energy Home (ZEH) is a home that produces all of the energy it requires over the course of a year. It can be powered by grid electricity and centralized natural gas, and will employ a combination of highly energy efficient design and high performance material components with renewable energy technology (usually solar thermal and photovoltaic, but not exclusively) to produce energy on site. This is optimized through the use of computer simulation, during the design process to assure that energy consumption is equal to or less than on site energy production from renewables.

As well, in Europe the Passivhaus concept is one initiated in Germany which strives to the same goals of the ZEH concept, promoting advanced energy efficiency techniques and materials to minimize the energy demand of homes as much as possible, so that a very small amount of onsite renewable energy can be employed to provide the necessary energy to the home.

These techniques require aggressive energy efficiency measures in temperate climate in order to achieve the low energy consumption goals, and with this is the risk that resources will be misallocated in ways that will not optimize the result in terms of energy performance and cost (Parker, 2009). For this reason optimization

software programs have been developed in the United States to give builders a tool to identify the least cost pathway to achieving the highest energy efficiency possible (Parker, 2009). The two main energy optimization tools in the US are *BEopt*, created by the National Renewable Energy Laboratory (NREL) and *EnergyGauge USA* developed by the Florida Solar Energy Center (Parker, 2009). These programs can evaluate various design and construction options towards the desired goal of zero energy along a curve of cost effectiveness.

Furthermore, the risks of attaining desired results in the design of low energy homes, especially in large residential buildings in temperate climates, justifies the use of energy modelling software in order to forecast the energy behaviour of a home or building so as to refine the design to maximize energy performance, comfort and cost effective energy conservation before it is constructed. There are hundreds of such software tools around the world today, but users need be aware as all energy modelling tools are not made equal (Mills, 2003). In general it is advised to avoid most web based tools as they tend to be less sophisticated and can therefore produce results which are unreliable and inconsistent (Mills, 2003).

The tools accepted and most used within the North American housing markets are non-web based, disk based tools produced by reputable engineering firms or National Laboratories. These are REM/Rate, by Architectural Energy Corporation (AEC), Energy-10 by NREL and Lawrence Berkeley National Laboratory and ResRatePro, by the Florida Solar Energy Center, ECOTECT, an AUTODESK product, amongst others. But not all tools can be utilized in all climates. It will be important for HOUSING SECTOR STAKEHOLDERS to fully investigate available tools for their appropriateness in specific climates and building styles before implementing any energy modelling efforts for sustainable housing plans.

A 2009 study reveals a very useful comparative case study that utilizes software energy modelling of single family homes in Indonesia (Utama & Gheewala, 2009). The study compares a typical conventionally built middle class home in the city of Semarang to several theoretical equivalent homes which incorporate varying techniques with locally available sustainable and low embodied energy building materials that are cost effective to use and feasible with the local workforce. The test homes also incorporated various low-tech efficiency measures to improve insulation and passive cooling. The aim was to optimize scenarios which reduce

energy consumption for cooling, whilst incorporating materials with minimal environmental impact in their production and transport.

It is important to note that the data used to determine the embodied energy of the building materials in this study was from previous studies of the authors' (Utama & Gheewala, 2009). There is no database for these values in Indonesia that can be easily accessed by others. Problems of data availability in developing nations is an important issue (especially relating to embodied energy of building materials) and is discussed further in Section 3.4.2 of this Scoping Paper.

In the Indonesian case study the baseline house energy consumption was measured using a software called ECOTECT (developed by architect and environmental scientist Dr. Andrew Marsh in 2000 (www.ecotect.com)). Comparing the measured data to the modelled data was done to verify the accuracy of the software. The modelled and measured data were shown to be within a few percentage points, demonstrating that the software model would be effective and accurate in that climate for those building types (Utama & Gheewala, 2009).

The results of the energy modelling in this case clearly demonstrated that locally available, sustainable, low cost and low embodied energy materials can be effectively deployed in hot-humid climates to reduce overall energy consumption for small residential homes (Utama & Gheewala, 2009). This is a powerful example of how energy modelling tools can enable low cost sustainable housing designers to achieve optimum energy results with the use of local sustainable resources in the design process. This leads to improved methods to reducing energy related emissions from cooling and from material extraction, production, and transport by providing informed decision making about best options. All of this leads to cost savings and environmental benefits along the life cycle of the building and its components.

Software tools are also advantageous because they can reduce human error and simplify complex calculations previously used to estimate solar gain, climatic characteristics, shading, heat gain/loss, indoor comfort and the various other variables incorporated within the computer models. For instance, the methods and calculations explored within the 1986 UNCHS (Habitat) paper entitled "*Case Studies on Measures for Energy Efficient Shelter and Infrastructure*" could, thirty years on, be easily, more quickly, and in most cases, automatically produced through the use of

an appropriate building energy modelling software tool. This makes for more efficient use of human and financial resources in the planning and design phase for sustainable housing projects.

There are limits, however, to what energy modelling can do. For instance, most commercially available energy modelling is not able to predict behavioural patterns of energy consumption within the household, but only the energy performance potential of the structure and operating systems themselves. Behaviour can play a very significant role in the overall energy performance of a home and must be addressed through other means, such as education, training and metering.

As well, energy modelling can add to upfront costs, with cost savings only realized later in the life cycle, often by the occupants who are often not the ones who invested in the modelling. This commonly known as ‘the split incentive’ and is a known challenge to many energy efficiency techniques.

Finally, it is important to understand that a well designed, energy modelled, building can be built poorly and miss its desired objectives, so high quality design work with energy modelling must be coupled with builder training and education in order to achieve the anticipated results. This can be particularly challenging in developing countries with low skilled labour force, but can be addressed through simple design and use of locally available materials and methods, as was the case in the Indonesian case study by Utama & Gheewala.

It will be increasingly important as UN-HABITAT expands its efforts to assist in the development of low cost sustainable housing, which effectively mitigates climate change, to employ methods of energy modelling in building design to maximize the effectiveness of the efforts they pursue. This must be done in concert with addressing the issues of occupant behaviour, the split incentive and construction quality so as to overcome challenges to success.

3.3.2 Quantifying the Carbon Footprint of Building Materials and Construction Techniques with Life Cycle Assessment.

The use of Life Cycle Assessment (LCA) is a growing trend in developed nations to bring better understanding to decision making around reducing the environmental

impacts of human activities. And a growing trend is emerging over the last decade for its use in building sector activities. (Haapio & Viitaniemi, 2008)

The purpose of LCA is to quantify the total impacts that a product or project will have on the environment over the course of its life cycle; generally from cradle to grave, cradle to gate or cradle to site (each of these distinctions accommodates different components of the overall life cycle). 'Cradle to Grave' quantifies all the energy and material inputs and impacts from raw material extraction, through manufacture, transport, and use to its eventual disposal and/or recycling. 'Cradle to Gate' quantifies these impacts to the completion of manufacturing, and no further. 'Cradle to Site' quantifies the impacts to the point when the material or product is delivered to its location of use.

Each offers a different perspective on the impacts. For the purposes of comparing construction materials it is useful to consider cradle to site values, but for building design comparisons cradle to grave is the appropriate metric. Cradle to gate can be used in lieu of cradle to site values if need be, as transportation impacts for embodied energy values can be estimated relatively easily by calculating distance transported and fuel consumption per unit of distance for the specific transport vehicle. This can then be added to the cradle to gate value. In the context of the comparing building materials, it is important to note that neither cradle to gate nor cradle to site consider the construction process, which can be a considerable contribution to the embodied energy of certain materials when incorporated into buildings. For low embodied energy materials such as soil blocks, the use of fossil fuel driven machinery to work with it, as compared to human labour, will have a dramatic effect on the overall embodied energy of that building material. Cradle to grave analyses will accommodate this aspect more thoroughly.

In addition to the building energy standards discussed earlier, ISO has set out ISO 14040, which now forms the basis of the LCA methodology. LCA is used in numerous applications around the world, but there exists a growing trend of use of LCA within the building sector to inform decision making towards sustainable development and to minimize the impacts that buildings have on our environment, including carbon emissions. ISO 21930:2007 is a standard methodology for the declaration of environmental performance of building materials, which can be used to establish the embodied energy/carbon of building materials. ISO 15392:2008 sets

the basis for a suite of new standards addressing sustainability in the built environment, including Life Cycle Assessment of building materials and whole buildings. Specifically interesting to efforts in developing countries is this standards provision to account for regionally specific criteria including social parameters, health issues, comfort, regional energy mix, alongside environmental impacts. Amongst the social criteria it can accommodate are issues of poverty alleviation, religion, and job creation. These criteria are potentially very useful for the assessment of building material and design options for efforts to establish sustainable low cost housing in developing nations.

Since the mid 1990's, UNEP has been focusing on LCA in the global context. In 1996, it released a report entitled, "Life Cycle Assessment, What it is and How to do it." Aiming to define and standardize the practice in a global context. In 2000, UNEP published a report entitled, "Towards a global use of LCA" in which the state of world affairs in the use of LCA and the challenges to its global deployment were discussed. In 2002 UNEP teamed with SETAC (Society for Environmental Toxicology and Chemistry) to form the Life Cycle Initiative, a group dedicated to the advancement of LCA globally. UNEP and SETAC are important resources and potential partners for UN-HABITAT in promoting the use of LCA to support low cost sustainable housing in developing nations.

Today there exist numerous tools for the Life Cycle Assessment of environmental impacts attributable to buildings. Different tools take different aspects and variables into account to varying degrees (Haapio & Vitaniemi, 2009); such as building energy consumption, water consumption, water and air pollution, and carbon emissions or global warming potential, among others. Each tool is designed for a certain user or specific output which can be applied in relevant industry practices. LCA tools are generally software based tools that rely on specific databases, or Life Cycle Inventories (LCI), of energy and environmental data attributable to the inputs of the product or project, and these are generally nationally or regionally specific. Unfortunately at present most software LCA tools are designed for use in European and North American markets (Haapio & Vitaniemi, 2008; 2009). For example, the University of Bath, UK has created the ICE Database (The Inventory of Carbon and Energy). This is a free LCI database of common building materials used in the UK. There are other databases as well which are discussed in Haapio & Vitaniemi, 2008.

The ATHENA Institute, a Canadian based not for profit research institution which provides LCA analysis and software tailored to the North American building industry has created the Impact Estimator for Buildings, a software based LCA tool which can quantify the environmental impacts of various building material and building design options. It does this within several categories including embodied energy and global warming potential. As well the institute has numerous studies and reports available as free downloads revealing the methodologies to attain those values for most commonly used building materials. The Athena Institute also has a comprehensive LCI database of building materials which is made available to purchasers of the Impact Estimator software (www.athenasmi.org). Several other LCI databases exist including SimaPro, GaBi and EcoInvent (www.pre.nl/simapro; www.gabi-software.com; www.ecoinvent.ch; respectively).

Because existing LCA tools are designed for and rely on environmental and energy data relevant to the region for which they are designed it is difficult and can potentially lead to incorrect results to apply them to areas for which they were not intended (Ortiz et al., 2009). This is because the energy fuel mix, power generation and manufacturing methods and technology, and transport and waste disposal systems for each nation or region often are very different. This is especially true between developed and developing regions in many cases. As well, most LCA tools that are designed for whole building LCA rely on specific algorithms based on relevant building systems within the regions they are designed for.

That said, virtually any LCA tool can be adapted and adjusted to suit specific building systems, such as the low tech, indigenous styles that may be employed in many developing regions. Some LCA tools may be better suited to being utilized in regions other than those they were designed for (Haapio & Vitaniemi, 2008) if their LCI databases can be replaced with data from the alternative region and algorithms representing local building techniques. The problem for many developing nations in this regard is that there is a significant lack of quality data for generating a suitable LCI database (Hertwich, 2005). For this reason Ortiz et al argue that although significant progress is being made with LCA in the developed world for the building sector, LCA techniques are not a “utopian tool” for rapid deployment in developing countries (Ortiz et al., 2009). That said, Ortiz et al., do go on to call for increased financial support and technical assistance to apply LCA methodologies in the field in

developing countries (Ortiz et al., 2009). Further research by HOUSING SECTOR STAKEHOLDERS on existing LCA tools would provide the basis for developing appropriate LCA tools that could be utilized in developing countries.

In addition, existing LCA tools and LCI databases can be used to create low carbon, low cost prefabricated housing to be exported from regions with appropriate LCA and LCI resources to developing nations in need. The tools would consider the impacts of the shipping aspect, and these could be compared to other options on the ground. This may in some cases be appropriate, especially in disaster relief efforts.

A study produced by Haapio & Vitaniemi in 2008 in Environmental Impact Assessment Review in 2008, entitled, “A Critical Review of Building Environmental Assessment Tools”, provides several comparative analyses of existing LCA tools to provide important insight into what may be the best options for sustainable housing developers interested in exploring uses of these tools in developing nations.

Important concepts when choosing materials based on LCA according to Bath University’s Sustainable Energy Research Team (SERT) (www.bath.ac.uk/mech-eng/sert/embodied):

- It is only appropriate to compare materials based on functional units not weight or volumetric units, as one material may require more or less weight or volume to perform the same function as another material. In order to equalize the embodied energy units we must first understand the translation of that into functional units between or amongst different material choices.
- As well some materials will have longer useful lives than others and so the embodied energy of one material choice must be equalized over time to others before a choice can be made.
- Maintenance requirements of different building materials will vary dramatically, and so this should be considered.
- Complex and highly intricate building products will have highly diverse and difficult to quantify energy/material inputs, and so can be assumed to be even more energy intensive than the commonly used embodied energy values.

There is at least one example within the academic literature of LCA techniques being used to quantify the embodied energy of a low cost sustainable home in a developing nation. The 2009 paper in the journal Renewable Energy, by Shukla et

al. entitled *Embodied Energy Analysis of Adobe Home* makes a meaningful attempt at calculating the total embodied energy of a home constructed predominantly of local, low embodied energy materials in New Delhi, India. The calculations used are mathematical and do not use LCA software tools, and provide some data which may be useful in other projects on the embodied energy of certain building materials commonly used in this region (Shukla et al., 2009).

It can be argued that, although LCI data to support LCA work in developing nations is generally lacking, and use of LCA tools designed for developed nations in developing nations can lead to incorrect outcomes, the data present within existing LCI databases such as the one at Bath University, United Kingdom, and others, can provide useful comparison of embodied energy profiles of building materials that can serve to inform sustainable housing developers in developing nations. Making general comparisons of relative embodied energy values can be used to minimize the use of typically high embodied energy materials in construction projects until such a time as comprehensive and regionally appropriate data is recorded, verified and compiled for use in more accurate LCA work. As well, life cycle thinking, that is, considering the chain of inputs and their associated impacts (social and environmental) required, can provide much of the insight needed to make appropriate decisions in the field. Comparisons of existing LCI data from developed countries shows that, although absolute figures vary, the relative intensity of embodied energy among common building materials (such as concrete, brick, soil and wood) are predictable. And when one understands the underlying reasons that a certain material tends to be higher in embodied energy than another, decisions in the planning and construction phases can be better informed to achieve what is likely to be the lowest embodied energy materials available, even without a formal Life Cycle Assessment. This is obviously prone to error, but in lieu of perfect LCI data, it can serve to minimize environmental impacts for construction projects. Key guidelines and principles that can serve this goal are outlined in Section 4.1.2 of this Scoping Paper.

3.4 The Clean Development Mechanism and the Built Environment.

Since the Marrakesh Accords in 2001 the parties to the Kyoto Protocol have created a carbon offset scheme known as the Clean Development Mechanism (CDM), which

aims to: reduce carbon emissions, and facilitate sustainable development in developing countries. It does this by allowing developed countries to invest in emissions reduction activities in developing nations in order to offset their own emissions.

Although the CDM has experienced exponential growth since its creation, there are persistent challenges for the utilization of carbon financing through the CDM for low cost sustainable housing projects. It is estimated that of the roughly three thousand CDM projects in the pipeline as of May 2008, there were only six of such projects within the building sector globally (most of which were in commercial buildings or residential retrofits) (Cheng, et al., 2008). Less than 1% of CDM projects currently are housing-related. This is due to many reasons including: the weak price signal of carbon in the building sector; and the dispersed nature of emissions from the building sector (i.e. a large number of buildings with small emissions per building), so that any one building project will have a relatively small emissions reduction profile, and thus a small carbon finance potential. This is a particular challenge in small scale low cost sustainable housing where small dwellings with small energy consumption habits dominate the indigenous building style, as Cheng (2008; pp ref) explains:

“As opposed to many other sectors, the building sector does not present a few big emission reduction options, but requires many small interventions in a very large number of buildings.” (Cheng et al., 2008).

The fundamental requirement that all CDM projects demonstrate proof that the emissions reductions are “additional” to business as usual activities is particularly troublesome to projects in the building sector. This proof of additionality in building sector CDM projects can be extremely difficult due to the fragmented, highly diverse and complex nature of the sector. This can make it “near impossible” to determine what aspects of a building design are truly additional as a direct result of carbon financing and not energy cost saving techniques which are appropriate in business as usual scenarios (Cheng et al., 2008).

These persistent issues have lead reputable researchers to conclude that carbon finance has, thus far, not provided any significant incentive for building developers to reduce emissions (Urge-Vorsatz, et al., 2007; Levine et al., 2007; Cheng et al., 2008).

The 2008 Seminal Paper published by UNEP and the Sustainable Buildings and Climate Initiative (SBCI), authored by Cheng et al. entitled “*The Kyoto Protocol, The Clean Development Mechanism, and the Building and Construction Sector*” highlights several potential and partial remedies applicable to the Low Cost Sustainable Housing projects, which HOUSING SECTOR STAKEHOLDERS should be aware of:

- Explorations of the Programmatic CDM are encouraged, but with caution. The Programmatic CDM allows project developers to streamline documentation and administration burdens by registering a “program” rather than a project, under which all projects that meet the approved criteria would be eligible for carbon finance.
- Recommendations for reform of the CDM to create new performance based methodologies better suited to the building sector. This would allow developers to “more easily employ indigenous technologies and locally developed materials”. A performance based metric will stimulate innovation towards best practices of emissions reductions that are cost effective, as opposed to prescriptive metrics which require certain actions or technologies regardless of cost effectiveness.
- Calls for standardized emissions baselines for sectors within regions or project types, thus reducing the administrative burden on small scale project developers to establish baselines for each project. The report goes one step further to call for common baselines developed specifically for low cost building projects. This reflects the difficulty present in demonstrating a net emissions reduction from sustainable development projects where the poor (who traditionally used little or no fossil fuel energy) would be lifted to have access to basic energy technologies (such as light, heat or modern appliances). This scenario actually will increase energy consumption within this population, but if this new energy demand is met with low carbon sources as opposed to conventional polluting sources, a net emissions reduction can be argued. In order to do so, the CDM Executive Board will have to accept hypothetical baselines of energy demand growth along business as usual projects as opposed to actual existing emissions baselines. This technique

can foster greater sustainable development, one of the key tenants of the CDM.

Recent work of the French research Institute, IDDRI (Institut du Développement Durable et des Relations Internationales) dated Nov, 2009 and entitled “Shaping Climate Policy in Urban Infrastructure: an Insight into the Building Sector in China” proposes an innovative use of the Programmatic CDM in order to support sector wide transformation through incentives paid to building developers for producing energy efficient buildings. These incentives could be monetary or regulatory, but would ultimately be supported and enabled through the pooling of Carbon Credits into a fund which could generate a substantial source of financing for such market transforming incentives (Li et al., 2009). This type of creative approach is what will be required of low cost sustainable housing developers who wish to find useful support from the CDM.

Although CDM reform has been on the agenda over the course of the last several Conferences of the Parties to the UNFCCC, currently there exist no approved methodologies that acknowledge the use of low embodied energy construction methods or materials which reduce greenhouse gas emissions compared to the use of conventional techniques over the life cycle of the building. This is a significant gap that HOUSING SECTOR STAKEHOLDERS could try to address.

Furthermore and regarding approved methodologies for the reduced demand for energy from residential buildings, there are only 6 small-scale methodologies and 5 standard methodologies. They are listed in table 3.4 below.

Standard Methodologies	CDM	Small Scale CDM Methodologies
AM0017 Steam system efficiency improvements		AMS-II.C. Demand Side energy efficiency activities for specific technologies
AM0018 Steam optimisation systems		*AMS-II.E. Energy efficiency and fuel switching measures for buildings
AM0020 Water pumping efficiency improvements		AMS-II.G. Energy efficiency measures in thermal applications of non-renewable biomass

AM0046	Distribution of efficient light bulbs to households	AMS-II.J. Demand side activities for efficient lighting technologies
AM0060	Power saving by replacement with energy efficient chillers	*AMS-III.AE. Energy efficiency and renewable energy measures in new residential buildings
		AMS-III.X. Energy efficiency and HFC-134a recovery in residential refrigerators

Table 3.4: CDM Methodologies applicable in the Building Sector.

Of these CDM methodologies there are only two which address whole building energy efficiency improvements: AMS-II.E and AMS-III.AE (marked with asterisks above). Further, only AMS-III.AE uses a performance based approach based on minimum efficiency standards (ASHRAE 90.1, in this case), allowing an integrated efficient design to act as the emission reduction activity, but acknowledges only electricity demand reduction and requires that all heating and other systems within the building be electric. This excludes the use of the methodology by residential project developers utilizing non-electrical energy sources such as biomass or gas. All other methodologies rely on technology specific applications to determine emissions reductions, making it difficult to calculate and thus integrate numerous low tech efficiency improvements (such as thermal mass and passive solar design). There are no existing methodologies which explicitly acknowledge the life cycle emissions reduction of energy efficient, sustainable building practices and low embodied energy materials use.

Recent developments at the COP-15 (Dec 2009) regarding CDM methodologies reveals that the CMP [Conference of the Parties acting as the Meeting of the Parties of the Kyoto Protocol] and the CDM Executive Board [EB] continue to be interested in improving access to the CDM by small scale energy efficiency projects within the building sector. At COP-15 the CMP authorized the EB to “prioritize, informed by an analysis of the use of methodologies and potential for emission reductions, the consideration and development of baseline and monitoring methodologies that are applicable to certain sectors, activities or regions in order to improve the efficiency of operation of the methodologies process.” (UNFCCC, 2009, Paragraph 11) And the CMP has requested the Executive Board to further work on the “consideration of the establishment of a positive list of sectors for which conservative criteria could be

used to assess additionality, initially for small-scale project activities in the renewable energy and energy efficiency sectors, as an alternative to using the additionality tool, taking into account appropriate project thresholds.” (UNFCCC, 2009, Paragraph 12.d)

Regardless of proposed reform to the CDM, existing or future methodologies or innovative use of Programmatic CDM, it remains important to understand that all CDM activities are based on quantifiable, measurable and verifiable reductions in emissions. Rigorous approval requirements involve a formal application, documentation, validation and verification process. This requires the use of third party verifiers (or Designated Operational Entities, DOE’s) and often warrants consultation with outside engineers and other professionals. For low cost sustainable housing, this can be an administrative burden which can significantly lessen the financial benefits of carbon finance. Regardless of future improvements to the CDM for building projects, emissions reductions must be quantified and verified in the field and thus will require advanced calculation and monitoring methods. Many of the software based tools discussed earlier in this chapter can aid in streamlining this quantification process.

HOUSING SECTOR STAKEHOLDERS should act in a concerted way to engage the UNFCCC CDM Executive Board and experienced CDM project developers to foster the creation of new methodologies specific to the residential building sector which are based on energy efficiency performance rather than prescriptive approaches, and which have simplified additionality requirements which are suited to the complexities of the building sector, and which minimise the administrative burden associated with validation and verification.

3.5 Foreign Aid and International Cooperation on Low Cost Sustainable Housing

Analysis of OECD data on international development assistance shows that in 2008 \$2million (US\$) was spent on low-cost housing provision (OECD ‘purpose code’ 16040). This was down significantly from the \$7 million spent in 2007. It is also very small in the overall context of \$13 billion in overseas development assistance spent in 2008 by OECD countries.(see <http://stats.oecd.org/index.aspx>)

The OECD also provides data on aid delivered with the purpose of climate change mitigation and adaption in developing countries (see http://www.oecd.org/document/20/0,3343,en_2649_34487_44221716_1_1_1_1,00.html).

In 2007 USD \$3.8 billion was spent in bilateral official development assistance (ODA) to help developing countries reduce their own greenhouse gas emissions (equates to 4% of total bilateral ODA) (note - this figure does not include multilateral aid – i.e. donations via UNEP, GEF and others). The largest donors were Japan (USD 1.3 billion), Germany (USD 0.8 billion) and France (USD 0.5 billion).

This funding contributed to sustainable development and greenhouse gas reduction in developing countries' energy, transport, water and forestry sectors. Unfortunately (and perhaps significantly), housing climate change aid is not presented as part of the detailed sectoral analysis of donations (although it seems probable that it falls under the 'energy' sector) (<http://www.oecd.org/dataoecd/18/8/44187916.pdf>).

Although 'housing' aid is not explicitly tracked, OECD aid is increasingly integrated with climate change markers that aim to qualify aid projects in terms of their benefits to mitigation and adaptation and track the motion of funds towards these efforts. And as of January 1, 2010, all OECD aid programmes are required to assess their proposals against a "Climate Change Adaptation" marker in addition to the already existing mitigation marker currently in use. This policy is intended to identify the donor's policy objectives clearly in terms of climate change, and to expedite allocation of funds towards increasing efforts to address the issue in developing countries.

But currently, there exists no internationally agreed upon standard for tracking the percentage of aid activity allocated to climate change adaptation or mitigation. (<http://www.oecd.org/dataoecd/32/31/44275379.pdf>). As adaptation efforts can be even more elusive than mitigation efforts, due to their usual integration with other environmental, social and capacity building benefits, it is even more difficult to quantify the amount of international aid which contributes to climate change adaptation (unless specifically identified as such). In fact, it is generally quite difficult to find specific data which details what foreign aid is used for (Easterly & Pfutze, 2008). Without a standard method to isolate and track such efforts, the

markers can serve to approximate the climate benefits of foreign aid and international cooperation (<http://www.oecd.org/dataoecd/32/31/44275379.pdf>).

The aggregation of aid in terms of sectors and in terms of climate benefits does not lend itself well to clarifying the amounts of moneys allocated to low cost sustainable housing projects which aim to mitigate and adapt to climate change, but it is important to note that there appears to be a trend away from large big investment projects in power, transport and telecommunications and toward projects in agriculture, rural development and social services including housing, education and health during this period. But, as mentioned, clear statistics are not readily available. (<http://are.berkeley.edu/courses/ARE251/2004/papers/Thorbecke.pdf>)

Aside from the problems associated with tracking the climate benefits of aid and especially those associated with housing, there are some important trends and issues in general which should be made clear as they relate to successful strategies in low cost sustainable housing. The full extent of the issues and complexities involved in foreign aid and international cooperation on sustainable housing are too vast to explore in detail within this Scoping Paper. Instead this study will explore some key examples of international cooperation and aid in sustainable housing, as a means to identify key challenges, success cases, and key organizations and initiatives that are suited to UN-HABITAT's agenda.

The ability to implement sustainable and replicable foreign aid programs that address energy efficiency and low cost, low carbon housing is marked by certain challenges. These challenges are often specific to national or regional conditions and therefore broad based prescriptive measures to improve access to and success of foreign aid can be ineffective. Instead, international efforts, when tailored to the key stakeholders and local conditions tend to be more effective, replicable and successful. This is especially effective when local stakeholder involvement is made a central design principle to a programme from its inception.

Regarding common challenges for developing nations in promoting low cost sustainable housing, insufficient management capacity coupled with lack of information and finance are very important. Foreign aid can fill the finance gap in some cases, but lack in human capital is recognised as one of the biggest obstacles to development (Goebel, 2007). An aspect of this is the limited regulatory frameworks that are capable of facilitating and supporting sustainable housing policy

in developing countries. As well, corruption and inefficient government can significantly limit the success of even well designed aid programmes (Werlin, 2005). Furthermore, lack of experience, expertise and capacity can lead to an inability to analyze innovative projects and can lead to a higher perceived risk of alternative technologies amongst decision makers in less developed regions. In addition to these common challenges for successful implementation of foreign aid and international cooperation, low cost sustainable housing programmes face many of the well known challenges to promoting energy efficiency common in both developing and developed nations. These include the split incentive, the rebound effect and the challenges of the first cost hurdle.

One of the key players is the Global Environmental Facility (GEF) which unites 178 member governments in partnership with international institutions, nongovernmental organizations, and the private sector to address global environmental issues (GEF, 2009). GEF projects are managed by the United Nations Environment Programme, the United Nations Development Programme and the World Bank. There are seven other international organizations, the GEF Executing Agencies, which contribute to the management and execution of GEF projects, the four regional Multilateral Development Banks (MDBs) the African Development Bank (AFDB), Asian Development Bank (ADB), European Bank for Reconstruction and Development (EBRD), Inter-American Development Bank (IDB). As well, the United Nations Food and Agriculture Organization (FAO), International Fund for Agricultural Development (IFAD), and United Nations Industrial Development Organization (UNIDO) contribute to the management and execution of GEFs projects. (www.gefweb.org)

There are many examples of housing projects the GEF have been involved in. For example, through their small grants program, in collaboration with UNDP, the Peoples Housing Cell and the Pakistan government, GEF has created 500 low cost, environmentally friendly, disaster resistant houses in Pakistan over the last 10 years. Known as the Benazir Housing Technology, it was implemented in Pakistan using compressed earth blocks, and solar energy technologies. The houses are able to be completed in 7 days using local builders supported by local NGO's. The cost per unit was \$3,900, and the houses were designed to be resistant to water salinity, earthquakes and cyclones. Furthermore technical capacity was increased through the 1,000 local masons that were trained in energy efficient technologies. The

Benazir Housing Technology is particularly applicable to the UN- HABITAT agenda as it is low in cost, energy efficient, environmentally appropriate and creates local employment. (<http://www.sgppakistan.org/>).

Another GEF project example, by the French Global Environment Facility (FGEF) is a project in China in collaboration with the French Government. French architects and engineers were coupled with Chinese housing developers to assist them in improving energy efficiency with the use of state of the art expertise and design tools. This programme has reduced energy consumption by 50% in 789,000 square meters of new housing (mostly affordable) since 1999 with only 7% additional construction costs than conventional building. The program objectives were to: reduce energy consumption by 50%; promote the development and enforcement of local standards and regulations, as well to promote technology transfer. Knowledge transfer enabled local Chinese governments to incorporate energy efficiency innovations into housing renovation projects, while supporting changes in building energy codes. In addition, economic development was enhanced in the production of new energy efficient building products, and two Chinese universities were able to develop energy efficiency training seminars for architecture students with assistance from French experts. Another aspect of the arrangement of the partnership that worked particularly well was that the Chinese developer who designed and financed the buildings remained the real project manager choosing the proposals they wanted to implement, French expertise was provided as an aid, but local stakeholders were the decision makers. The French continued to support the developers from design through the construction process, and into final marketing and sales. In addition to attaining cost effective efficiency improvements beyond business as usual methods, certain regulatory barriers were overcome and capacity was built. From the success of the project, plans are to continue renovation projects and begin work in rural areas (FGEF, 2003).

The World Bank is also a key player in financing a great deal of the sustainable development initiatives. The World Bank is made up of two unique development institutions owned by 186 member countries, the International Bank for Reconstruction and Development (IBRD) and the International Development Association (IDA). Each institution plays a different role, but they play a collaborative role in advancing the vision of the World Bank for inclusive and sustainable

globalization. The IBRD focuses on the reduction of poverty in middle-income and creditworthy poorer countries. The IDA focuses on the world's poorest countries. Their work is complemented by the International Finance Corporation (IFC), Multilateral Investment Guarantee Agency (MIGA) and the International Centre for the Settlement of Investment Disputes (ICSID) (www.worldbank.org). Like the World Bank the International Monetary Fund (IMF) is an organization of 186 countries and it works to promote sustainable economic growth, foster global monetary cooperation, facilitate trade and to reduce poverty. (<http://www.imf.org/external/about.htm>)

There are many other relevant initiatives in the broad area of sustainable development and buildings conducted by the United Nations. To touch on a few, the Sustainable Building and Construction Initiative (SBCI) a UNEP led partnership between the UN and public and private stakeholders in the building and construction sector promotes sustainable building practices globally as does UNEPs agenda 21 for sustainable cities. (www.unep.org/sbci/index; www.unep.org/DOCUMENTS.MULTILINGUAL/default.asp?documentID=52). The UNDP Millennium Development Goals set strong targets to end poverty by 2015. The UNECE has had successes towards energy efficient housing in the European member states using passive solar design, local affordable non toxic materials, as well as policy and regulatory reform, technology transfer and the development of financial mechanisms.

3.6 Overview of Key Issues for Developing Nations: Gaps and Challenges

As is evidenced through the discussions in the previous sections, there are significant gaps and challenges which developing nations face in realizing the benefits associated with maximising energy efficiency in housing, but certain success stories highlight ways forward. In particular, the lack of building codes and standards which support efficiency and sustainability, the challenges of access to advanced design tools, determination of regionally appropriate life cycle inventory data, access to the CDM and challenges to international aid are relevant and are summarised in this section.

Lack of sufficient human and financial resources and insufficient or inconsistent enforcement of sustainable building policies within developing nations, including emerging economies, is a complex and important challenge to the successful implementation of building energy codes or efficiency standards. Lack of a well documented track record for LEED or BREEAM inspired approaches to housing in developing nations, also is a gap which can be filled through seed funding and demonstration projects.

Regarding the use of building energy modelling to measure the impacts of housing on climate change, the challenges faced by developing nations again revolve around capacity. It is not likely that many impoverished communities will have access to advanced design tools such as energy modelling software and the computer technology or expertise needed to use them. But UN-HABITAT and its partners can offer significant assistance in bringing these design tools into the design process on behalf of local stakeholders. This can most easily be done, and at least cost, in the creation of regionally appropriate designs and prototype plans which can be easily replicated in the field, avoiding the need to employ expensive or technologically advanced tools repeatedly in the field. These notions of regionally appropriate design and prototype plans are discussed further in Chapter 4.

Another significant gap is the lack of or poor quality of data for use in LCA tools for quantifying the embodied energy of materials or building designs. Although there are some examples of embodied energy data being generated in certain developing countries (Indonesia, India), there remains a widespread lack of sufficient data to utilize LCA tools on a mass scale for these nations. UN-HABITAT may choose to work with partner organizations to increase access to meaningful LCI data for developing nations, closing this gap. This effort may require significant resources and time to develop, but would serve well to improve decision making on environmentally benign housing options. Until LCI data is made available in these regions, LCA thinking (in lieu of actual data) amongst local builders and designers can be used to minimize environmental impacts from housing.

Within the international framework of climate change mitigation under the Kyoto Protocol building efficiency projects remain marginalized. The lack of appropriate methodologies for low cost sustainable housing is a very important challenge for accessing carbon finance by these types of projects. As well, there are other

significant challenges for the inclusion of low cost sustainable housing in the CDM, especially for small scale projects, including administrative costs, a weak carbon price signal in the building sector, and issues of demonstrating additionality. It will be increasingly important for HOUSING SECTOR STAKEHOLDERS to work closely with the CDM Executive Board and CDM project developers to promote new methodologies which properly recognize residential building energy performance and the GHG impacts of building material choices. Simultaneously, HOUSING SECTOR STAKEHOLDERS should explore avenues to utilize the new Programmatic CDM in innovative ways to foster widespread support for housing through carbon markets.

In addition, there are key challenges to the successful deployment of foreign aid and international cooperation aimed at promoting low cost sustainable housing. Currently, there is no standardised method to track aid in terms of housing and climate change, and this limits the ability of researchers to analyse the effectiveness of climate efforts in housing related aid. Regardless, aid efforts must be careful to ensure stakeholder enrolment early in the process so as to maximize acceptance and integration while simultaneously building local capacity to advance efforts without aid.

These are some of the key gaps and challenges faced in advancing low cost sustainable housing for many developing nations and are important considerations in efforts by HOUSING SECTOR STAKEHOLDERS and their partners towards their goals. In the following sections, this study will go on to explore in more detail best practices in design, building materials and methods as they pertain to low cost sustainable housing.

4. Appropriate Building Materials and Techniques

4.1 Best Practices for Climate Change Mitigation

Proven methods to mitigate climate change within the housing sector are to reduce energy consumption, and thus greenhouse gas emissions, during the useful life of the building and to minimize life cycle emissions associated with building materials and techniques. In order to achieve these goals it is important to implement regionally appropriate energy efficient design utilizing low embodied energy materials, and make use of onsite renewable energy within an energy efficient structure. It is important to understand when designing homes and choosing building methods that it is often the case that a building's total life cycle greenhouse gas profile can be 2/3 to 3/4 in the energy use over its life with the remaining portions in the embodied energy of the materials, although this is not universally the case. Depending on the construction method, the materials, design and location the embodied energy in the materials can be a much more significant contributor to the overall life cycle climate impact of the dwelling. It is also important to consider the relationship between the housing and the community at large. Within the scope of sustainable urban planning (touched on in section 4.4.3), integrating sustainable planning with sustainable housing design can support numerous synergies which improve economy wide climate change mitigation, as well as adaptation and social benefits. In the following sections, this study will explore some important strategies to address both reduced energy use and reduced embodied energy in building design, as well as address the climate adaptation potential of low cost housing within an integrated design model.

4.1.1 Regionally Appropriate Energy Efficient Design

Based on the climatic conditions and the local population that a home is constructed in, it will be important to address energy efficiency and occupant comfort according to the ambient climatic conditions and the thermal comfort expectations of the inhabitants. With future climate change, these regional climate conditions look set to change, adding further complexity. A design which may serve to efficiently reduce energy consumption while providing comfort in one climate zone may not necessarily

do so in another climate zone. An issue for many developing nations is that formal “climatic zones” that detail climate characteristics have not yet been identified or established. Most cities in the world, including within developing nations, have historic records of basic geographic, weather and climatic data, including wind speed and direction, humidity, temperature, latitude and other factors. As well the World Meteorological Organization has established climatic data for many regions (Grigoletti et al., 2008). Climatic data forms the basis for determining general climatic characteristics which can be used to identify climatic zones (Rakoto-Joseph et al., 2009). Establishing climatic zones where they have not been established before is an important step in optimizing energy efficient building design for those areas (Rakoto-Joseph et al., 2009). From this point bio-climatic building design can be achieved with precision (Rakoto-Joseph et al., 2009; UNCHS, 1986). Bio-climatic design can be described as building design which emphasizes energy efficiency through passive heating and cooling systems and which is informed by quantitative climatic data and human comfort data for optimization.

In the case where formal climate zones have not been established, basic weather and climate data as described above can be used to establish a basic data set to inform design. In general, most inhabited areas of the earth can be categorized within a few informal climate zones, such as temperate, cold, hot-humid and hot-arid. There are, of course, important nuances to locations which are disregarded in this basic framework. But for the purposes of scoping the most effective energy efficient design techniques, as they may be applied to low cost sustainable housing to effectively address climate change, this study will generalize the key techniques and their usefulness within general climatic zones. In the field, it is important to design housing strategies which will be more accurately optimized to local climatic conditions than is presented here. The descriptions below are only to highlight important strategies to be considered, but should be further optimized in real world applications with advanced energy modelling and LCA tools. For that reason the following design methods are explored in terms of their general appropriateness to climate zones and a discussion follows regarding perceptions of comfort. With regional climate change expected in the lifetime of new homes (20-60 years) it is vital that building techniques that seek to address both climate change mitigation *and* adaptation are used. Of the climate mitigation building techniques outlined below, we also therefore given an indication of their suitability/appropriateness to

withstanding gradual changes in climate and climatic extremes (floods, heat waves etc.), in other words, their potential to adapt to climate change.

Passive Solar Heating: Ideally suited to temperate and cold climate zones. Well-suited to climate adaptation.

Passive solar design for heating is a well-known and established set of methods in use around the world. Much work has been conducted on the establishment of guidelines for passive solar design since the 1970's. There are numerous reference materials available on the web and in the scientific literature. Important resources are listed in the following section. Generally, passive solar design utilises the natural solar radiation in a given location to warm the interior environment of a home or building. This is accomplished through the proper orientation of the building towards the equator, with adequately sized window glazing to allow winter solar radiation (sunlight) into the home. When properly designed, this passive technique will serve to warm the interior mass of the building materials in colder seasons without overheating in warmer seasons. It is important to provide properly designed overhangs or shading, which is specific to the latitude of the building location, and serves to maximize solar heat gain in the colder months while minimizing solar heat gain in the warm and hot months (as the sun angle changes over the seasons). A properly design passive solar home will remain cool during heat waves, which are expected with increasing frequency with climate change. Passive solar heating requires an integrated design which incorporates a highly efficient building envelope (with adequate insulation and minimal air infiltration or thermal bypass) and adequate thermal mass on the interior of the building. This integrated approach can assure that a home or building is able to maintain comfortable temperatures throughout the year with minimal energy inputs for heating and ventilation.

Thermal Mass: Ideally suited to temperate, hot-arid and hot-humid climate zones. Well-suited to climate adaptation.

Thermal mass describes the heat absorptive capacity of building materials. As mentioned above, thermal mass can be utilized in passive solar design to adsorb solar radiation. High thermal mass materials include, stone, concrete, earthen blocks, earthen plasters, bodies of water and other dense materials. Thermal mass

materials have the ability to regulate interior temperatures for heat and cooling alike. They function best for heating when surrounded by a highly insulated building envelope. As any heat absorbed by the material will gradually radiate out over time, and if there is an efficient envelope around the space that heat will be retained within the space for the enjoyment of the occupants. As well, thermal mass materials have a long lag time in releasing and absorbing heat. For this reason if thermal mass is used properly in a home or building it can serve to moderate temperatures during times of limited solar gain, by slowly radiating stored heat. For the purposes of cooling, thermal mass, if never exposed to direct heat radiation from the sun, cooking appliances or other sources, will remain very cool for long periods of time, providing a cool interior environment for occupants in hot climate zones, again a useful feature with an expected increase in warming under climate change. Building with Adobe earthen blocks have been demonstrated to be very effective at improving thermal mass in buildings, and are a low embodied energy material which can serve to reduce the life cycle emissions of a building, especially for offsetting energy intensive cooling.

Natural Ventilation: Ideally suited to hot-humid and hot-arid climate zones. Well-suited to climate adaptation

Natural ventilation describes a number of potential techniques which make use of natural convection currents within air flow to direct air into and out of buildings in such a way as to expel heated air from the space and replace it with cooler air or exchange air without losing heat or cool. One example of this would be to design air ducts which allow air to enter low in the building via underground ducts, while simultaneously allowing air to escape high in the building. This technique captures the natural convective currents of rising warm air to draw cooler air into the building, which replaces warm air, providing cooling with no or minimal mechanical parts or energy consumption. The Benazir Housing Technology, used in Pakistan by projects funded by GEF and administered with the help of UNDP and local organisations, uses a design which takes advantage of passive cooling through ventilation in pyramid shaped raised roof structures.

Evaporative Cooling: Ideally suited to hot-arid climate zones. Poor to moderately suited to climate adaptation.

Evaporative cooling describes numerous techniques which utilise water's natural conductive properties to transport heat out of the building via evaporation. Common techniques include maintaining moist surfaces (roofs or walls) that are exposed to the exterior environment and sunlight. The evaporation of water produces a cooling effect (as in human sweat) and can successfully serve to cool building materials which in turn will cool interior ambient temperatures. The effectiveness of this technique was demonstrated in a case study in India, featured in the 1986 UNCHS report entitled, *Case Studies on Measures for Energy Efficient Shelter and Infrastructure*.

There are also, mechanical technologies which use the evaporation of water to produce cool air for circulation in the home. These technologies require electricity to operate, but can be effective. Passive evaporative cooling is a preferred method, but requires caution so as to avoid water infiltration and damage to building materials. Passive evaporative cooling works best in hot-arid conditions where the gradient of humidity is great forcing more evaporation to take place in a shorter period of time. Because of expected increases in water scarcity with climate change, however, this technique does not rate highly in relation to climate change adaptation.

Other Passive Cooling Techniques: Suited to hot-arid, hot-humid and temperate climate zones. Suited to climate adaptation.

There are numerous low tech and passive techniques which can serve to reduce the ambient temperature within buildings in during warm seasons. These include solar shading, high albedo wall and roof surfaces, vegetative shading and micro-climate enhancement, vegetative roofs and wall trellises and appropriate spatial design to isolate interior heat loads, especially from cooking. In general, for hot and temperate climates, avoiding overheating is important to comfort and reducing energy inputs associated with air conditioning or mechanical ventilation, especially under conditions of future climate change.

Providing adequate shade, as covered porches, patios or courtyards, can serve to provide additional living space and reduce the heat gain associated with direct solar exposure. This can be achieved through the construction of shade structures attached to the home, and through strategic plantings of vegetation and trees. Vegetation provides not only shading but an enhanced micro-climate which is cooler

than non-vegetated areas; this can serve to reduce interior temperatures within homes as well as their immediate surroundings (Kumar & Kaushik, 2005). High albedo materials, that is, materials which have a high solar reflectance, will reduce solar heat gain and help to maintain moderate interior temperatures. These include highly reflective or light coloured roofing and wall materials, such as lime plastered walls or galvanized metal roofing. All of the above mentioned techniques need to be considered within the framework of an integrated design which is appropriate and optimised to the local conditions.

High Performance Building Envelopes: Appropriate to all Climate Zones

As is evidenced by global efforts in developing advanced building energy codes and designs, the building envelope plays a very important role in the energy performance of buildings. There exist numerous guidelines and standards (as discussed in section 3.2 of this Scoping Paper) which address efficiency in the building envelope. In some regions there are limitations to the availability of high performance insulation or highly efficient windows and doors. This will limit the applicability of some aspects of advanced building design guidelines in relation to a high performance building envelope. Regardless, a well constructed and properly designed home will aim to achieve the most energy efficient building envelope possible with available materials and expertise.

Energy Efficient Mechanical Systems: Appropriate to all Climate Zones

Although that goal of any regionally appropriate energy efficient design should be to maximize passive, low tech and zero energy techniques for attaining comfort in the home, it is often necessary to also provide some mechanical systems to supplement heating and cooling methods. There are a growing number of products and building mechanical systems on the market today which are designed to be highly energy efficient. For instance the US Department of Energy's ENERGY STAR program for appliances and lighting has gained international acceptance and a growing market share. In the EU, mandatory energy performance labelling for appliance and other household items provides numerous product options which are designed to minimize energy consumption. Depending on what region of the world, and under what trade agreements that region is, it may be difficult or impractical to acquire energy efficient

mechanical systems for a home. The access to standardized energy efficient products is a complex trade issue which is very important, but cannot be adequately explored in this Scoping Paper.

It remains important when designing low cost sustainable housing for developing nations to minimize energy consumption attributable to appliances, electronics and mechanical systems for the home. Each region, its economic situation and access to products will dictate to what degree energy efficiency can be attained with available products. Regardless, the design strategy should always be to minimize the need for energy consumption through proper design, and thus the reduction in sizing or elimination of mechanical heating or cooling equipment in order to achieve the desired results. Building energy modelling can serve to minimize the sizing of mechanical systems in home design so as to assure that energy consumption can be reduced.

Regionally appropriate energy efficient design can attain dramatic results. This is especially true when advanced design tools, such as the ones discussed in Chapter 3 of this Scoping Paper, are utilized to fully optimize energy performance and construction methods and materials in housing (Parker, 2009). The emerging trend of “Zero Energy Homes” as described in section 3.3 of this Scoping Paper is example to this fact. Properly designed homes which account for climatic conditions, employ low cost passive design features and execute state of the art energy efficiency techniques can be constructed to require a minimal amount of energy inputs to maintain comfort and produce 100% of the energy inputs required by the use of onsite renewable energy, usually photovoltaic (PV), solar thermal collectors and micro-wind or micro-hydro. A zero emissions (Zero Energy) housing sector should be the ultimate goal of all housing efforts today, especially in low income developing nations where energy costs and quality of life concerns are paramount.

The 1986 UNCHS paper entitled, *Case Studies on Measures for Energy Efficient Shelter and Infrastructure* sheds light on several key design factors discussed above that were implemented in Hot-Humid, Hot-Arid and Temperate climate zones within developing countries. The case studies explored in the paper utilize bio-climatic design principles in India, Turkey and Mexico. The findings of the paper are completely relevant today and can be referred to for in depth analysis on specific techniques as they were applied in the case studies.

Also, a 2009 study by Rakoto-Joseph et al., entitled *Development of Climate Zones and Passive Solar Design in Madagascar*, explores in detail the methods and best practices of developing regionally appropriate energy efficient design in a developing nation which previously lacked any formal climate zone identification or successful efforts in bio-climatic design. This study provides valuable insight which may be applied in other developing areas.

There is a 2008 study by Grigoletti et al. entitled *Analysis of the thermal behaviour of a low cost, single family, more sustainable house in Porto Alegre, Brazil* which details methods of bio-climatic design used to optimize the energy and comfort performance of a low cost home in Brazil using regional climate data. The study also demonstrates that thermal mass is a critical component for regulating temperatures in both hot summer and cold winter seasons (Grigoletti, et al., 2008).

Important to all of the above described cases of bio-climatic design are human perceptions of comfort which can vary dramatically from person to person and group to group. It is often the case that people who are accustomed to extreme heat or cold, humidity or dry will have very different perceptions of comfort as compared to those who are not accustomed. What this means is that there may be some advantage in exploring this issue for designers of energy efficient housing so as not to over-design. It also highlights how close attention to regional climate change scenarios will be increasingly important for low cost sustainable housing provision. There can be significant cost savings in not over-designing certain heating or cooling systems, whether they are mechanical or passive. If a home is adequately designed to the expectations of the intended occupants, certain measures may be reduced thus reducing costs.

4.1.1.1 Short List of Key Resources [See Ch. 6. References for full listing]

- www.epa.gov/hiri/mitigation/coolroofs.htm
- The Passive Solar Energy Book. By Edward Mazria, 1979.
- Sun, Wind & Light: Architecture Design Strategies. By G.Z. Brown, 2001.
- Chapter 6 of The Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. By Levine, et al., 2007.
- Permaculture: A Designers' Manual. By Bill Mollison, 1988.

- Case Studies on Measures for Energy Efficient Shelter and Infrastructure. By UNCHS (Habitat), 1986.
- Development of climate zones and passive solar design in Madagascar. By Rakoto-Joseph et al., 2009.
- Analysis of the thermal behaviour of a low cost, single-family, more sustainable house in Porto Alegre, Brazil. By Grigoletti et al., 2008.

4.1.2 Low Cost and Local Low Embodied Energy Materials

As was discussed in section 3.3.2, determining the embodied energy of building materials can be a complex process. And currently there is insufficient data on the embodied energy of building materials within developing countries. Although LCA tools are important to accurately quantifying the embodied energy of building materials, if the means of achieving this quantification are not accessible to housing developers in developing countries then certain guidelines can be used in lieu of hard data.

Existing LCI databases from various regions around the world can be used as rough guides for identifying the probable relative intensity of embodied energy between common building materials. For instance it is generally understood within the academic literature that wooden structures tend to have a lower embodied energy than concrete buildings (Gustavsson & Sathre, 2006). As well it is generally the case that earthen, unfired adobe bricks will have a lower embodied energy than cement or fired clay brick products, due to the minimal energy inputs required for creating adobe blocks relative to the alternatives. And it is also generally the case that clay fired bricks will have a lower embodied energy than cement based blocks (Utama & Gheewala, 2009). And lime products will generally have a lower embodied energy than cement based products. Although these are generalizations, and the embodied energy of materials will differ in their absolute values from region to region, in lieu of hard data it remains useful to use a life cycle mindset to evaluate in relative terms which materials are most likely to have a lesser environmental impact than others.

Key Principles in Lieu of LCI Data:

- Only utilise materials that suit the needs of the project in terms of structural characteristics, thermal performance and durability so as to assure structural integrity, energy efficiency and longevity of the project.
- Choose materials with a minimum of complex integrated parts, generally the more complex and diverse in material inputs a product or material is, the more embodied energy is represented within it (www.bath.ac.uk/mech-eng/sert/embodied).
- Choose materials that are minimally processed, i.e. are in their natural state or altered with minimal energy inputs. Examples are stone, raw timber, earth and straw.
- Choose materials which are locally available and are not transported over long distances to the construction site from the site of extraction or manufacturing.
- Choose materials which do not have significant environmental or energy implications in their extraction or manufacture, i.e. heavy mining, destructive logging, high energy processing, or massive water use. And which are sensitive to the local environmental vulnerabilities of the area from which they are extracted.
- Choose materials and design options which reduce the overall quantity of Portland cement without reducing the structural integrity of the construction, i.e. substitute concrete, mortar and cement based plasters for clay, earthen based or biomass based materials such as wood, bamboo, adobe or compressed earth block, or utilize substitute pozzolans .
- Choose products and materials with recycled content, and materials which are re-used.
- Choose renewable materials over scarce finite materials. Biomass based building products are inherently renewable (wood, straw, bamboo, bagasse) mined materials generally are not.

Some relevant examples of often locally available low embodied energy materials which are applicable to low cost sustainable housing in developing nations are listed below.

Adobe or compressed earthen block

Masonry building blocks constructed of either formed and sun dried clay soil, or mechanically compressed clay soil. A building material well suited to Arid and Semi-arid climates, where abundant clay rich soils are present.

Earthen and lime based plasters and floors

The use of natural clay soils, with or without Lime stabilisers to produce wall plasters or finished floors which are moderately durable and very low in embodied energy. Usually the higher the lime content, the more durable. Well suited to any climate, as long as exposure to rain/snow is minimised by adequate roof overhangs. Well suited for interior walls and floors.

Pozzolan alternatives to Portland cement

The use of fly ash from coal combustion, volcanic ash, and/or agricultural ash can be used to offset the total quantity of Portland cement required in concrete and mortar mixtures. Portland cement is a very high embodied energy product, and so should be minimised where possible with these alternatives. In most cases, the proper use of pozzolan alternative to Portland will not degrade the strength of concrete or mortar mixtures.

Straw bale construction

Relevant examples include the work of World Hands Project and Paksbab. See references below. Agricultural waste straw which remains after the harvest of grains is often burned or discarded in landfills. It can however be compressed into bales through mechanised or human powered means to produce a highly insulative wall material that is easily plastered and can provide highly energy efficient building envelopes when properly constructed. See www.paksbab.org for case studies on low cost sustainable construction with straw bales in Pakistan. Paksbab also has a how to manual on low tech, human powered methods for compressing straw into bales suitable for construction.

Appropriate use of stone

The use of stone, especially stone which is not quarried, heavily processed, or transported over long distances, can be a source of local low embodied energy building material. When properly constructed, the material can be extremely durable

to climate stresses including cyclone, flood and high wind. It is not, however, well suited for exterior wall construction in cold or temperate climates without additional insulation, as its very high thermal mass can reduce energy efficiency if un-insulated. Its thermal properties are well suited to hot climates, especially when shielded from direct solar heat gain.

Locally harvested rough sawn lumber

Wood products of all types are inherently renewable, although destructive logging practices in sensitive ecosystems is known to have serious negative effects on biodiversity and environmental quality. Usually, locally harvested timber which is done in a sustainable manner can provide excellent building material. Furthermore, if that timber is minimally processed (left in its natural state, or only milled slightly) it can offer a very low embodied energy and renewable building product. Also, when constructed into durable, long lasting structures, wood building products (which are carbon rich) act to sequester CO₂ within the building, slowing or eliminating the natural decomposition of that CO₂ back into the atmosphere.

Recycled or reclaimed building materials

Anytime a building material can be salvaged from a previous use, this represents a life cycle savings in environmental impacts. The elimination of the extraction and processing aspects of a products life cycle can significantly reduce its overall environmental impact to a building project. The use of reclaimed bricks, aggregate for concrete mixtures, pallet wood for wall and roof structures (see www.worldhandsproject.org for examples), and the reuse of doors, lumber or other building materials can save costs and minimise environmental impacts associated with housing construction. It is not advised to re-use outdated or inefficient mechanical systems for heating cooling or ventilation, or poor quality building products which can reduce the durability, safety or longevity of a building. Quality control guidelines for reclaimed or recycled materials are important.

Bagasse, hemp, bamboo and other biomass products

As with wood products, the use of other biomass based building products can reduce life cycle impacts, promote sustainable renewable land use and sequester CO₂ within buildings. Bagasse (waste biomass from sugarcane), hemp, bamboo, straw,

wood pulp and other biomass materials are increasingly being used to manufacture durable building materials including, plywood, masonry blocks, insulation and other useful products. Distance from extraction and manufacturing to the building site should be considered as should the extend of energy intensive processing when choosing such products. The study by Utama & Gheewala, 2009 explores in detail some of these examples, see references below.

The 1986 UNCHS paper entitled, Earth Construction Technology is an excellent manual detailing the basic principles of soil science and characterizations of soil for use in construction. The manual claims to be a review of the basic principles of earth application, but focuses primarily on methods of stabilizing native soils with additives, natural and man-made, to increase the usefulness of soil for construction. It is not a useful tool for the application of soil as a building material, or a manual on the proper techniques of earthen construction. Appropriate manuals and key references are listed in the following section.

Paksbab, Pakistan Straw Bale and Appropriate Building is an organisation based in California that works closely with local stakeholders in rural Pakistan to assist local populations to develop sustainable straw bale housing at a very low cost. The organisation has created a useful manual detailing a low tech method for creating straw bales useful for building without machinery. This technique is proving to be useful to local rural populations in recycling agricultural waste into useful building materials (www.paksbab.org).

4.1.2.1 Short List of Key Resources [See Ch. 6. References for full listing]

- Influence of material selection on energy demand in residential houses. By Utama & Gheewala, 2009.
- Embodied energy analysis of adobe house. By Shukla et al., 2009.
- Building with Bamboo. By J. Janssen, 1995.
- Environmental effects of structural solutions and building materials to a building. By Haapio & Viitaniemi, 2008.
- Variability in energy and carbon dioxide balances of wood and concrete building materials. By Gustavsson & Sathre, 2006.
- www.bath.ac.uk/mech-eng/sert/embodied

- www.worldhandsproject.org
- www.palosantodesigns.com
- <http://undp.org.pk/undp-wins-accolades-for-its-energy-efficient-low-cost-housing-solution-the-benazir-model.html>
- www.paksbab.org

4.1.3 On-site Renewable Energy Technologies

On-site renewable energy technologies can be extremely effective at providing life enhancing improvements such as lighting and hot water for impoverished areas while serving to mitigate climate change by limiting the increase in fossil fuel consumption associated with increased energy consumption. These technologies are particularly useful in developing nations where energy infrastructure is lacking and fossil fuel energy is in limited supply or prohibitively expensive (Demirbas & Demirbas, 2007).

There exist a variety of technology options which harness renewable energy that can be supported by and integrated with low cost sustainable housing design and policy. These technologies include biomass fuel, solar water heating, photovoltaic technology for electricity (PV), micro-wind or micro-hydro technologies to produce electricity and bio-gas generation for heat, power or hot water. Impoverished communities may face challenges in the adoption of these technologies because of the initial costs for the advanced equipment. With any of these technology options, it will be very important to consider issues of availability of replacement parts and the technological knowledge to operate and maintain the equipment over time, and the economies of scale which can be gained in community sized projects. These challenges can be overcome in part with the assistance of aid efforts and economic development.

The Global Environment Facility (GEF) promotes, among other things, small scale solar technology deployment for households and communities in developing nations, through financing mechanisms and partnerships. Examples include solar water heating for households in Tunisia, off-grid household photovoltaic installations in 68

countires, community scale PV in India and the Philippines and 171 small scale bio-gas projects in rural India (GEF, 2009).

Small-scale bio-gas generation is being used throughout Latin America, Asia and India to produce renewable fuel on the household, farm or small community scale. The use of biomass waste from agriculture, industrial processes as well as animal or human waste can be digested in a semi-controlled environment, usually a ferrocement tank with some mechanised mixing devise and limited exposure to air, to generate methane gas which can be burned to produce heat for hot water, space heating, cooking, lighting or electricity generation. Although this low tech method is being used in small scale applications around the developing world, some studies suggest that a higher level of economic efficiency is attainable in a larger industrialised scale (Vijay et al., 1996), others indicate that small scale bio-gas efforts, when properly designed, provide numerous benefits to local inhabitants including increased sustainability, climate change mitigation, energy independence and economic development (Demirbas & Demirbas, 2007; Hessami et al., 1996).

In a 1996 study, Hessami et al propose a low-tech bio-gas digester design to be implemented in small scale applications. This example is one that can be used to pilot and refine bio-gas renewable energy projects for low cost sustainable housing initiatives.

Other technologies for the use of solar energy for water heating are well known and in use around the world including the Caribbean, Asia and Africa. These include small, low tech “batch heaters” for heating water with the sun. These can be fashioned from recycled materials such as old window glass, discarded refrigerators and steel barrels. Low tech batch heater technology is particularly suited to the tropical climates that many developing nations are situated in (Langniss & Ince, 2004).

As well, photovoltaic technologies for electricity and, in particular, lighting have been very effective at improving the human condition in impoverished regions while reducing the climate impacts of energy use. There are numerous examples of projects to implement PV in developing countries, some more successful than others. A comprehensive review of the successes and failures of over 20,000 examples of PV projects in Kenya is provided in the paper *The (Quiet) Energy Revolution* by Acker & Kammen, 1996 (Acker & Kammen, 1996).

4.2 Best Practices for Climate Change Adaptation

4.2.1 Overview of Regional Climate Change Vulnerabilities and Adaptation Capacity

According to the Intergovernmental Panel on Climate Change (IPCC), the world is likely to experience many impacts associated with climate change regardless of present or future mitigation efforts. This is the result of the inherent inertia within the earth's climate system and the historical greenhouse gas emissions already present in today's atmosphere (IPCC, 2007; Hansen, 2008). These unavoidable impacts make effective efforts to provide adaption to a changing climate and its associated extreme events equally important with greenhouse gas emissions mitigation.

The contribution of Working Group II to the Forth Assessment Report (4AR) of the IPCC highlights the likely impacts, adaptation opportunities and vulnerabilities of the world's human and natural environments, and is detailed by region and by ecosystem. Web access to the Working Group II contribution to 4AR is available at http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm . The IPCC's Forth Assessment report is regarded as the definitive scientific consensus on the issues of climate change available today.

According to the IPCC, it is expected that global impacts including the intensity of storm events are likely to increase, sea levels will rise, ocean temperatures will rise, and the occurrence of summer heat waves will increase in severity and frequency. Furthermore, changes in historical weather patterns, winter snow precipitation, glacial melt and seasonal temperature patterns are expected to change. These impacts will negatively impact biodiversity and alter the historical patterns of vector born and other diseases and pests, as well as food and water security.

To summarize the key issues likely to impact developing nations, below is a brief overview by region adapted from the IPCC 4AR.

AFRICA:

Due to increased temperatures and changes to rain and snow patterns, water stress is expected to increase for between 75 and 250 million African people by the year 2020. Food security is expected to be severely compromised for many African countries, with agricultural yields expected to decrease by as much as 50% by 2020.

Rising water temperatures in lakes and coastal areas is expected to further diminish food supplies, through reduced production of local fisheries.

By the end of the 21st century, rising sea levels will threaten to inundate low lying coastal areas, many of which are heavily populated. This will likely lead to mass migrations and substantial economic losses. Housing will be a central issue in this regard.

Existing vector born and other diseases and pests are expected to shift in their range and impacts on human settlements.

According to the IPCC, Africa is one of the most vulnerable regions in the world due to multiple expected impacts and very low adaptive capacity.

ASIA:

Over the next two to three decades, increased glacial melt in the Himalayas is expected to increase flood probability, and dramatically alter historical water supplies. Fresh water availability is expected to decrease as a result. This may adversely affect over 1 billion Asian people by the year 2050. The risk of hunger due to changes in crop yield and rain patterns is expected to remain very high in several developing countries.

Expected sea level rise and coastal flooding of megadelta regions, especially in Bangladesh, will likely cause substantial disruption to ecosystems and populated areas.

These impacts coupled with rapid urbanization in Asian cities will compound pressures on natural resources and will likely have significant impacts on sustained economic growth for the region.

Disease is expected to be exacerbated by warming temperatures and ocean water, cholera and diarrheal diseases are expected to increase.

LATIN AMERICA:

Dramatic changes to the Amazon rain forest are expected, due to reduced soil moisture and increased temperature. The increased threat of forest fires is likely. Rainforest will likely give way to grass land savannah in this region by mid century. Species extinction and biodiversity loss will increase.

Melting glaciers and changes in precipitation will adversely affect water supplies and increase water scarcity for Latin American people. In arid regions, crop and animal yields are expected to decrease, significantly reducing food security.

Expected sea level rise will impact coastal areas, and increasing ocean temperatures will adversely affect coral reefs and fisheries, adversely impacting food supply, and the fishing and tourism industries.

Due to limited adaptive capacity within impoverished areas, impacts are expected to be felt quite dramatically in the region.

SMALL ISLANDS:

Due to the low elevation of many small island states, these nations are among the most vulnerable to climate change and rising sea levels.

Coastal erosion and impacts to coral reefs and fisheries will produce significant disruptions to these regions. Storm surge and sea level rise threatens critical infrastructure, housing and economic development. Limited fresh water resources will be further diminished by increases in temperature and changes in rain patterns.

In general, developing nations are expected to shoulder the brunt of climate change impacts. This is due to several factors including, lack of economic development and the associated infrastructure to improve adaptive capacity, and existing situations in food and water security which already push the envelope of safety and human health. These extreme conditions will only be further exacerbated by increased stresses from climate change. Forced migrations due to extreme climate events such as drought and coastal inundation will further stress political and cultural tensions. And the existing stresses of limited access to health care, emergency services and basic infrastructure for safe water, sanitation and shelter will dramatically limit the capacity of developing nations to handle additional stresses resulting from climate change. Lack of adaptive capacity is a critical issue facing all developing areas of the world today.

In addition to the IPCC 4AR, there are other important resources available which highlight these important impacts for developing nations and the importance of adaptive capacity. These include the 2009 UNFPA report entitled *The State of*

World Population 2009, and the 2008 UNFCCC publication entitled *Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries*.

The current body of knowledge agrees that sustainable development can improve the abilities of developing nations to adapt to climate change, but there are significant challenges to this on many levels including growing climate stresses themselves. Improvements to housing and infrastructure will play an important role in increasing adaptive capacity. Low cost sustainable housing is an area which can address many adaptation issues by building capacity in a bottom up approach.

4.2.2 Durability and Resilience Planning

Adequate housing design, which aims to increase climate change adaptation capacity, must address the issues of durability and resilience in regard to extreme events, expected impacts and natural disasters. Low cost sustainable housing design must aim to meet the needs of people and communities to remain resilient in a changing environment in ways that increase food and water security (discussed in sections 4.2.3 and 4.2.4 below) and provide safety of shelter and infrastructure. Durability and resilience planning aims to forecast worst case scenarios and engineer those threats into the building design and material choices to mitigate damage risks to the structure.

Proper building design for seismic activity is a classic example of durability and resilience planning. Buildings constructed according to engineered guidelines to resist seismic shock will generally remain intact or minimally damaged in the aftermath of an earthquake. Conversely, buildings constructed without the knowledge or foresight of seismic risk pose a significant public safety hazard, and can produce substantial economic losses and waste of precious natural resources, as has been seen in Pakistan, Haiti and numerous other regions. The same line of thinking that can produce earthquake resistant housing can be applied to climate change adaptation.

For instance in coastal areas, it will be crucial to provide detailed analysis of flood risks and to promote construction in least risk areas, and in ways that are designed to be flood and cyclone resistant. Building in low lying flood prone regions should be avoided. Construction on fortified stilts to allow rising waters to flow freely under

dwelling is a practice well known to many indigenous peoples of the world. There is much work today in the promotion of cyclone resistant housing in developing and developed nations. Habitat for Humanity, UN-HABITAT, USGBC and other organisations have been engaged in cyclone (hurricane) rehabilitation efforts in Samoa, Philippines, Bangladesh, Thailand, New Orleans and other regions. In some cases indigenous building styles are being utilised to produce cyclone resistant housing, which are low cost and low in embodied energy (UNISDRR, 2008) these indigenous techniques include the use of stone construction for flood and wind resistance. Other techniques employ modern building styles with steel reinforced concrete, brick or other masonry. It will be important to balance low embodied energy materials (like stone or others), with cost effective and durable building methods which are low in embodied energy and energy efficient. There is an important tension between modern construction methods to increase durability (with steel and concrete) and the need to achieve the same goals of resilience through the use of low cost sustainable building materials. There are significant benefits to employing techniques that promote permanent, durable housing (while minimising LCA impacts) rather than lightweight construction designed to be easily replaceable when extreme weather events occur. The social benefits of permanent, resilient housing are that households can safely endure extreme events with reduced risk of injury, loss of property and potential displacement. The costs and benefits of climate change mitigation (with efficient low embodied energy buildings) and durability (with engineered, reinforced construction) and social implications (low cost, permanent vs. Replaceable, and safe) must be carefully weighed with intimate stakeholder involvement on a community by community basis. In many cases Indigenous methods can serve to inform decision makers, while revealing synergistic methods to attain the goals outlined above.

Indigenous knowledge can be utilized to increase adaptive capacity and security of lasting shelter in areas likely to experience increasing and changing flood and storm risks. Modern engineering can further enhance the techniques so as to accommodate the worst potential storm surge or flood expected within the usable life cycle on the building. As well, choice of materials should be appropriate to the risk factors of a given locale while minimising LCA climate impact. Durable and water resistant materials can serve to allow structures to survive extreme flood events, and allow occupants to maintain the structural integrity of their housing through high

winds. Adequate foundations to resist water infiltration and minimize settling within saturated soils will be important in flood prone regions.

As is advocated in the LEED for Homes building system, it is wise to assess a building location and proposed design for natural threats, current and future, before construction so that durability planning can become a design criteria before the inhabitants are committed to a construction project which may fail them as a result of increased climate stresses (USGBC, 2007). For example, USGBC has been working closely with New Orleans's rebuilding efforts to promote Flood and Hurricane resistant building techniques. These include homes on stilts and mold resistant building materials, such as paperless drywall (www.usgbc.org/Docs/News/CGI%200909.pdf).

Flooding and Storm damage are not the only climate stressors to be considered. Fire resistant building materials such as earthen block can serve to allow dwellings to survive forest or brush fires, even if inhabitants are forced to temporarily evacuate the area. Returning to a home with minimal damage is very beneficial.

Flooding, fire; extreme winds, extreme precipitation, drought, and extreme heat are all factors which must be considered when planning for durability and climate resilience. And the changing threats of climate change must be accommodated in design criteria to assure lasting housing that serves the people. Durability and resilience planning requires that building techniques be tailored to the inherent environmental threats and anticipated future threats of climate change.

4.2.3 Water Security through Rain Catchment and Re-use

Aside from air, water is the most vital resource for human life; in fact all life on earth is dependent on a consistent clean source of water. Lack of safe drinking water is a primary concern in many least developed regions, and is a significant contributor to health and sanitation issues which have far reaching social, economic and environmental implications. As well, the expected yields of important agricultural crops are expected to be impacted through reduced water supply for irrigation, changes in rain patterns, changes in snow melt patterns, reduced soil moisture and increased temperatures (IPCC, 2007). Climate change impacts are projected to dramatically affect the availability of water resources for millions of people.

Regions that currently experience drought or water scarcity will be further restricted by changes in climate, as well, regions who currently have limited but ample water resources are likely to increasingly face water scarcity beyond historical limits. Flooding and inundation of coastal and riparian areas will also have important impacts on water quality, salinity and thus water security. Water is a necessity for virtually all aspects of human life and therefore any efforts to improve adaptive capacity in sustainable housing must also consider water security.

The issues of water security are too vast to explore in detail in this Scoping Paper, and involve complex issues of infrastructure, finance, policy, efficiency and technology development. For the purposes of this study, an exploration of low tech, small scale and sustainable water resource management systems useful on the household scale follows.

There are effective, sustainable and low cost methods to improve water security on the household and community levels which integrate very well with sustainable low cost housing techniques already discussed. Much work has been done around the world to identify, implement and test low cost rainwater catchment, filtration and water re-use systems in the context of both developing and developed nations.

A very useful method for improving the availability and security of water is in the collection and storage of rain water, or snow melt, from rooftops or other hardscaped surfaces. This can be done in a wide array of techniques from totally passive, simple and inexpensive to complex, mechanized and increasingly expensive. For the purposes of maximizing use of economic resources in impoverished communities it is obviously preferable to focus on those methods which produce the greatest benefit for the least cost and with the least complexity in maintenance and operation.

Collecting rainwater is an ancient and well known technique utilized for centuries by indigenous cultures around the world. Modern development practices of the last 100 years have often overlooked this vital practice, but growing climate stresses and population growth have fostered a growing revival and improvement on the ancient practice. Africa and South-East Asia, in particular, have advanced water catchment implementation in response to a growing need and lack of access for clean water (Gould & Nissen-Petersen, 2006). Kenya and Thailand, for example, have become focal points of innovation in the art, and countries including China, India, Iran and

others are actively pursuing advances in technology to increase the use of rain water harvesting to meet growing needs (Gould & Nissen-Petersen, 2006).

Roof catchment of water can easily utilize passive gravity fed methods to bring fresh water down from the roof to a safe distance from the dwelling and foundation and into a beneficial soil infiltration area or storage container to be used to meet various needs. Numerous low tech and low cost techniques to utilize available rain water resources are explored in the comprehensive manual *Rainwater Catchment Systems for Domestic Supply*, by Gould and Nissen-Petersen. The focus of the book is the implementation of water catchment systems that can be used to meet the primary or supplemental water needs of households. It reviews several case studies from around the world, and comprehensively covers all aspects of design and construction. These include system sizing, gutters, material options, construction methods operation and maintenance. The book explores both technical and non-technical issues with water catchment, including cultural, health, water quality, institutional, gender and training. This exceptional design, construction and implementation resource explores numerous techniques used throughout developing nations, and constitutes an excellent *how-to* manual that can be used by designers and builders in the field to provide durable, adequate and useful water catchment systems in low cost sustainable applications.

Examples include the use of simple sheet metal, wood or bamboo gutters to direct rainwater from roofs into containers. Containers can be fashioned from re-used barrels (which have been thoroughly cleaned), large clay pots, large plastered baskets, plastic or galvanized tanks, ferro-cement tanks or ferro-cement reinforced dug holes. Ferro-cement refers to a simple technique used in many developing regions to build a waterproof tank structure on site with limited skills and material inputs. The technique requires some form of steel reinforcement (which can be as simple as barbed-wire or metal poultry fencing) and cement mortar. A cage of steel is constructed and a very dense, high cement content mortar is applied to the frame to create a vessel. The technique is easy to construct and unskilled labour can be easily trained to build these sturdy reliable vessels.

Rain water catchment for drinking should include some simple safety and filtration methods to assure safe drinking water. This includes “first flush” methods where the initial wash off of the catchment surface is diverted away from the catchment basin

(by a passive, automatic system) to divert contaminants, then water is allowed to flow directly into the storage vessel. Once stored, rain water should be shielded from direct sunlight to avoid algal growth, and water can be extracted from a floating outlet which is designed to extract from the top third of the water, but below the water surface. This region is regarded as the cleanest as it avoids floating particles as well as sunken sediments.

This water is ideal for cleaning or cooking, but for drinking it is advisable to run the water through a filtration and purification system. These include porous clay, carbon or sand filtration and UV or chemical based sanitation. These and other purification techniques are explored in detail in Gould & Nissen-Petersen's book previously mentioned.

There are numerous other resources listed at the end of this section and in the bibliography. Art Ludwig, in 2005, produced a technical manual on water storage, design construction and health which explores many low tech methods as well as state of the art advanced techniques. There is also a technical manual developed by the US based Texas AgriLife Extension Service, which comprehensively reviews more advanced and intensive methods of catchment, storage, filtration and distribution which can be applicable to larger community based systems in developing nations, although the manual is intended for a primarily US audience, many of the methods are applicable anywhere.

Once a reliable source of safe drinking water is established, the key principle that should be considered in any efforts to improve water security is that all water resources, including precipitation and waste water (greywater), should be harnessed to provide multiple functions which benefit the inhabitants and their surroundings before that resource is allowed to dissipate into the environment. For instance, rainwater can be used to clean vegetables, then captured and re-used to clean clothes and finally directed to irrigate fruit trees or other beneficial vegetation. The same volume of water has thus been used to provide at least three functions before it was dissipated. This is known in the permaculture lexicon as "stacking of functions" and is a key principle that can be applied in the efficient use of many resources within the sphere of low cost sustainable housing.

Permaculture is a sustainable land use school of thought and design methodology originally promoted and advanced by Bill Mollison. Mollison is the author of several important books and manuals pertaining to sustainable water, land, and other resource use for humans. Permaculture has gained international recognition and has grown into a movement spanning all continents with many applications for sustainable development within developing nations.

In regards to water security, stacking of functions can take the form of strategically designed, but low tech, methods for diverting catchment overflow and greywater away from living spaces and into recessed basins constructed to collect surface water under thick beds of mulch where beneficial plants are allowed to thrive. This can add to food security if these plants are edible or provide food or forage (discussed further in Section 4.2.4). This can also increase shade and cool microclimates for passive cooling efforts, provide habitat for beneficial pollinators and predators that can protect food crops from pests, and provide improved biomass resources for fuel or construction materials (bamboo).

Principles and guidelines for implementing these passive and mutually supporting designs for safe water re-use and landscape enhancement are explored in detail in several key publications and manuals, including Mollison's *Permaculture: A Designer's Manual*, Brad Lancaster's two part *Rainwater Harvesting for Drylands and Beyond Vol. 1 & 2*, and Art Ludwig's three complimentary manuals *Building an Oasis with Greywater*, *Builder's Greywater Guide* and *Branched Drain Greywater Systems*. All are listed in the following resource list.

4.2.3.1 Short List of Key Resources [See Ch. 6. References for full listing]

- www.akvo.org
- www.arcsa.org
- Rainwater Catchment Systems for Domestic Supply, by Gould and Nissen-Petersen, 2006.
- Permaculture: A Designers' Manual. By Bill Mollison, 1988.
- Rainwater Harvesting: System Planning. By Mechell et al., Texas Agrilife Extension Service. 2009.,
- Branched Drain Greywater Systems. By Art Ludwig, 2000.
- Builder's Greywater Guide. By Art Ludwig, 1995.

- Create an Oasis with Greywater. By Art Ludwig, 1994.
- Water Storage tanks, cisterns, aquifers and ponds. By Art Ludwig, 2005.
- Rainwater Harvesting for Drylands Volume 1. By Brad Lancaster, 2006.
- Rainwater Harvesting for Drylands and Beyond Volume 2 By Brad Lancaster, 2008.

4.2.4 Food Security and Urban Agriculture

Food security is closely tied to water security, and as water is made more abundant food production can more easily be achieved. As with water security, the issue of food security is a very complex one which this study does not attempt to explore in its many important and inter-related facets. Instead the study will highlight some of the easily attainable, low tech and low cost techniques which can be employed on a household or small community level to enhance food security and that are relevant to low cost sustainable housing methods.

Even with limited water resources, in arid and semi-arid regions, food security can be enhanced by simple and low tech design enhancements that support native beneficial vegetation and livestock and are integrated with sustainable housing design and water catchment and re-use methods described in the previous sections. Improving vegetation in the immediate surroundings of a home can provide multiple benefits to the inhabitants which include food, forage for livestock, passive cooling, protection from winds and beautification, all of which enhance quality of life.

Home gardens can provide a significant source of high nutritional value (vitamins and minerals) foods that may not be affordable or readily available otherwise. Intelligent and low tech landscape design which channels excess rainwater (overflow from catchment) and greywater from household use into vegetative areas can substantially increase the yields of small scale urban agriculture (Lancaster, 2008; Ludwig, 1994).

In addition to smart water management the proper selection of native and beneficial plants can stack functions benefiting food production as well as passive cooling, forage for livestock and biomass fuels or building materials (bamboo and others). Composting of organic materials, soil enhancement with manure and mulch and spatial planning to support small scale agriculture are important strategies which can

improve the adaptive capacity of household towards improved food security, and may also provide economic benefits through the sale of value added products produced in the home. Beekeeping, as an example, can provide ample honey to a household plus wax, pollen and excess honey which all can be sold into the local economy further improving a household's quality of life and adaptive capacity through economic growth.

Cuban efforts to promote small scale urban agriculture and community composting have gained international recognition and acclaim for improving food security within the nation and promoting economic development for the under-privileged (Korner et al., 2008). Furthermore, Liberia's government has elevated community based alternative agriculture to a matter of national security, having developed a comprehensive food security agenda in 2008 which aims to support community based approaches (Liberian Ministry of Agriculture, 2008). A study of urban small scale dairy farming in Mexico City reveals that, such practices support increased employment, urban green space, improved bio-diversity and improved food security for local residents (Losada et al., 2000).

According to Jeremiah Kidd of San Isidro Permaculture, (a sustainable land use contractor who works closely with several NGO's in Africa), public schools in Malawi are beginning to enact efforts to increase food security for students. With the assistance of foreign aid from Germany, schools are implementing water catchment and intelligent landscaping projects which support small scale gardening on the school property. The produce is then made available to students, improving student nutrition, health and learning. These techniques are being taught to other teachers from other schools and the efforts are being expanded.

Low cost sustainable housing initiatives should, and can easily be integrated with household and community level food and water security efforts.

4.2.4.1 Integrated Housing Design with Living Structures

Beyond food security, sustainable water and landscape management can be used to provide important functions to increase the energy efficiency of housing design.

As previously mentioned, vegetation can provide shade and thus passive cooling for homes, plus shelter from winds and sources of biomass fuel and food. Housing design can support sustainable landscape design, as it can actually incorporate living building components into the structural design of homes. For instance the proper use of green roofs or vegetative shading has been demonstrated to improve indoor comfort levels (USGBC, 2007; Kumar & Kaushik, 2005). As well, trellised shade structures which are design to support food producing vines can create covered shaded areas to reduce solar heat gain to the home in hot climates when properly designed and located. These living structures can be raised horizontal structures, such as covered courtyards, armadas or patios which increase usable outdoor living area and can also be vertical structures covering exterior walls of homes and buildings. In either case, the leaves of the vine or vegetation will intercept solar radiation before it contacts the building envelope, greatly reducing heat gain and subsequent need for cooling (Kumar & Kaushik, 2005). Strategic planting can obstruct winds and protect homes from potentially damaging high winds, improving durability of the structure, and reduce cold air infiltration associated with high winds, improving thermal comfort and reducing heating inputs.

An integrated sustainable design should optimize all available benefits from water and vegetative resources to improve and enhance food and water security, energy efficiency and durability of the structure with the use of low tech and low cost techniques.

4.3 The Importance of Regionally Appropriate Design

The success of any low cost sustainable housing development depends on the ability of the designer to generate buildings that respond to the determinants of the localized context. Design parameters change with every site and due to the fact the differences are often subtle or hidden, they are often overlooked and as the result those projects will ultimately fail to create effective living environments which adequately address climate change mitigation and adaptation while supporting the local inhabitants. The value and extent of these determinants will also vary with different cultures. Only in depth research and input from local stakeholders can uncover these all important rhythms.

John Turner in his book “Housing for People” compares the lives of people living in shanty towns to those in a new, modern housing development. What he found is that the new housing actually made the lives of the inhabitants more precarious because it was too expensive, detached from the work centres and the social life for most people and did not allow incremental additions or revisions to the building. Although the people living in the shanty towns had substandard living conditions, they paid no rent, were close to their work, food markets and their families. They had more options available to them and more ability to handle a crisis when it occurred due to their support system. This seems counter-intuitive to conventional thought on slum and poverty alleviation. The ironic findings of Turner’s work reflects more upon the potential failures of well intentioned but poorly designed housing projects, than upon any argument of the benefits of informal sub-standard slum housing.

The importance of stakeholder enrolment in an integrated design approach is further highlighted in the case of a US based NGO, World Hands Project, and its efforts to build low cost sustainable houses in Juarez, Mexico. The project was designed to utilise reclaimed and recycled materials including reinforced tire foundations, straw bale walls, and recycled pallet wood to construct structural roof trusses. The buildings were well designed by taking advantage of passive solar design, a high performance building envelope and low embodied energy building materials (including natural earthen plasters). The project was meant to be a model for ongoing housing to be built in the area that would be embraced by the local population. What occurred was that this particular building model, although it functioned well, was ultimately rejected by the local stakeholders because the straw bales were too difficult to acquire and transport, and the look of the earthen plaster was viewed as a material only the least advantaged would use. The design was later changed by World Hands Project to accommodate the input received from the local inhabitants. The new design used recycled pallets for the walls, a common method of building in the area, stuffed with waste straw obtained for free from a local livestock yard and a lime plaster that the residents approved of. The new buildings were embraced by the local population and therefore more often replicated by locals outside of the program.

According to Alfred von Bachmayr, director of World Hands Project, what was learned in the process was that his design team had intended to produce a regionally appropriate design but had not understood the preferences of the local stakeholders before the program began. Therefore, the original buildings failed to be fully effective for the people involved. Had the people been included in the design of the buildings early on the extra step of a redesign could have been avoided.

This highlights a critical issue in the implementation of low cost sustainable housing and regionally appropriate design. Local stakeholders must be allowed a central role in the design and planning of the housing systems to be employed. Without direct and effective stakeholder enrolment, low cost sustainable housing projects run the high risk of being ineffective and un-replicated, making the efforts a waste of time and resources.

Key Aspects of Regionally Appropriate Design with Stakeholder Consideration

- Project must assure access to clean water
- Bio-climatic design utilising passive, low tech methods and renewable energy
- Improve regionally appropriate climate adaptive capacity
- Provide collection of rainwater for domestic uses, growing food and watering animals.
- Provide intelligent landscaping to utilise waste water and promote beneficial vegetation
- Design with comfort levels that are acceptable to the intended inhabitants
- Design must consider cultural attitudes regarding the materials, methods, spatial and aesthetic design
- Financial limitations of inhabitants should determine design limits
- When appropriate improve access to innovative finance, such as micro lending, as a means of building financial strength amongst the owner-occupants
- Support community involvement in projects to promote ownership
- Utilise local NGO's to assist in gaining input from local stakeholders
- Site selection to improve access to local resources including markets, agricultural land, employment, transportation and social centres
- Allow for flexibility of design allowing future additions or alterations by owners within a prescribed framework

The aspects listed above include the basic needs of the people, the physical determinants of the site and the climate, along with social and cultural aspects of the people and the community. In addition the aspects that affect the larger world are included along with the inclusion of ways to empower people and alleviate poverty.

4.3.1 The Benefits of Standardized Guidelines and Prototype Plans by Region

When regionally appropriate designs are implemented with strong stakeholder approval, these successful cases should be replicated as much as possible. One way that this can be fostered is through the development of standardised guidelines and prototype plans which are tailored to the local conditions. Standardised guidelines should encourage as many of the key aspects detailed in the previous section as is feasible and should aim to encourage an integrated implementation approach with local stakeholders. The support of local organisations should be encouraged in order to obtain the essential information needed for the design of the buildings and procedures to enrol the owners and community in the creation and maintenance of the structures.

Furthermore, each climatic region will have conditions which will necessitate prioritization of certain design elements over others. Bio-climatic design as discussed in the 1986 UNCHS (Habitat) paper entitled *Case Studies on Measures for Energy Efficient Shelter and Infrastructure*, and other papers cited in Section 4.1.1, is crucially important. As is evidenced by the design of all modern building energy codes, each climatic region requires a specific set of guidelines that are tailored to the common conditions of that region. For instance the insulation or passive solar gain guidelines appropriate to temperate or cold regions will not serve cost effectively in hot-humid or hot-arid regions. Energy efficient design for colder regions justifies the prioritization of highly insulated building envelopes with optimized solar gain for passive heating. Conversely, energy efficient design for hot-arid climates will require prioritizing solar shading, passive cooling and natural ventilation.

A relevant study presented at the 23rd Conference on Passive and Low Energy Architecture in Geneva in September 2006, explores the potential of prototype plans

to provide low cost sustainable housing with multiple benefits. The study entitled, *A Very Low Cost Sustainable Housing Prototype for Tijuana Mexico*, explores the numerous WIN-WIN-WIN synergies that can be accomplished in sustainable design. The design incorporated several synergistic aspects of food and water security, energy conservation, bio-climatic design and stakeholder involvement and focused on the use of local sustainable materials, passive heating and cooling and adaptation to local geographical conditions (La Roche, et al., 2006).

The creation of prototype plans that are easily accessible and understandable to local builders and self-help owner-builders is a potentially effective tool explored in the 1980 UNCHS (Habitat) paper entitled *Building Codes and Regulations in Developing Countries*. The paper contends that prototype building plans of low cost housing can lead to the step by step improvement of to the built environment in local communities (UNCHS, 1980). Very recently, a coordinated effort by several NGO's (including, RESET, Practical Action and Brac University) to develop flood and cyclone resistant prototype homes and buildings in Bangladesh, made use of multi-lingual and graphically depicted instruction manuals and building plans which were more easily accessible to the local stakeholders (<http://practicalaction.org/reducing-vulnerability/docs/ia1/seminar-dec-2009/posters/esrc-poster-3-reset.pdf>). Prototype drawings and 'How-to' manuals can be coupled with actual full scale model homes so that local populations can become familiar with the construction and the final product. Prototype plans must be carefully created, not only to ensure sustainability as discussed throughout this Scoping Paper, but also to assure "readability" by under-educated work force personnel. In many cases illiteracy and ignorance of construction standards leads to non-compliance and dangerous construction execution (UNCHS, 1980). In light of this challenge, prototype plans should aim to be simple, in context to local building normative behaviour and graphically depicted as much as possible so as to maximise understanding and acceptance amongst under-educated builders. Furthermore concerted efforts to train and educate the local workforce will be critical. Model home demonstration projects offer exceptional opportunities to educate people throughout the entire population, including government officials, engineers, architects, builders, labourers and home owners.

Generally, successful indigenous building styles and specific techniques that have traditionally served the needs of the people in terms of comfort, safety and durability

should be integrated with advanced design tools for optimizing energy conservation and building performance. Again, this re-emphasizes the importance of bringing the local stakeholders to the centre of the design and construction process, so that locally accepted and highly successful strategies can be supported and improved upon with state of the art building science and design tools through a standardised approach.

4.3.2 The Role of Local Indigenous Knowledge and Self-Help Methods

As previously mentioned indigenous knowledge can be used to inform the design of buildings by identifying key climatic issues, local customs and common relationships to living space and family structure. In a time when climate change is a major driver for developers of low cost sustainable housing to improve their methods and design models, the knowledge of the indigenous population is a valuable resource which cannot be overlooked. Many indigenous cultures have adapted their lifestyle without the luxury of abundant energy supply for cooking, heating or lighting. They instead have developed practical tools to utilize the native resources around them to meet their basic needs. It is true that in many cases energy poverty is a serious detriment to quality of life and is something which deserves being alleviated, but important low tech, natural and zero energy methods employed by indigenous peoples must not be dismissed as primitive in the effort to advance low cost sustainable housing. Many of these methods can serve as models to be improved upon with appropriate technology, and scientific design criteria.

The 2008 UN/ISDR (International Strategy for Disaster Reduction) report entitled *Indigenous Knowledge for Disaster Reduction* highlights numerous case studies from indigenous populations in developing countries around the world. These case studies demonstrate many ways in which indigenous knowledge, building techniques and low tech self-help lifestyle methods have proven to alleviate deleterious effects from climate and other disasters including drought, fire and flood. It also highlights ways in which modern scientific knowledge can be coupled with traditional indigenous knowledge to improve adaptive capacity of local populations.

UNCHS (Habitat) produced a report in 1985 entitled, *The Use of Selected Indigenous Building Materials with Potential for Wide Application in Developing*

Countries. The report is limited to alternative cement products and cement substitutes, focussing primarily of materials which can be mass produced. It fails to review the broad spectrum of indigenous building materials (or methods) which can be successfully applied in developing countries.

Indigenous methods are almost always self-help methods, as few indigenous populations have had the financial resources to outsource the labour inputs associated with constructing housing. Self-help methods offer a means of empowerment to the local community, especially when local methods can be supported and further optimized with input from experience sustainable design professionals. These methods are extremely important in the creation of low cost housing due to the fact that when people have a role in the creation of their homes, they tend to feel more of a sense of ownership. When they add their own touches to the buildings and work together with other owners, the projects will ultimately prove to be more successful and better cared for.

Alfred von Bachmayr of World Hands Project states that he has observed that projects created without any involvement of the local inhabitants in the design and construction, tend not to be replicated, and in some cases abandoned. The self-help methods have been widely utilized successfully in micro lending where borrowers are grouped together and help each other complete their obligations. Self-help can be used as a tool to build community between the different cultural, ethnic and religious groups involved in the projects.

The Aranya Low Cost Housing Project in Indore, India, is one example of where the poor were given the opportunity to shape their own environment and due to its success, it has become a research and training institution used by students of sociology, planning and architecture; government agencies; building professionals and donor agencies (Serageldin, 1997).

4.4 The Importance of WIN-WIN-WIN Synergies

Within housing projects there is a great capacity for synergistic relationships to form that increase the positive effects within multiple inter-related arenas. These include climate change mitigation (i.e. the reduction of greenhouse gas emissions), climate

change adaption (i.e. improving the resilience and resistance of housing to climate effects such as flood, extreme storms and increasing temperatures) and social sustainability (i.e. increasing local capacity for sustainable growth and poverty alleviation, job creation, education and improved quality of life). Within housing there are many examples of techniques that can foster improvements across all of these arenas with reduced and highly efficient use of inputs and costs.

4.4.1 Principles and Examples for Climate Change Mitigation and Adaption (WIN-WIN'S)

As was discussed in earlier sections, Climate Change mitigation is a side benefit of good design, especially in terms of energy efficiency and low embodied energy materials. When buildings are constructed of materials found in the local environment, and utilise renewable energy for the energy needs, while maximizing use of rainwater and recycled water for the water needs and irrigation for growing plants, the impacts of those buildings on the environment are minimized. The best examples of sustainable development and Climate Change mitigation are achieved through integrated design, where the goals for the project are achieved through an integration of all the disciplines involved from the outset of the design of the project through the construction and occupation.

It is important to consider stacking functions when developing plans for low cost sustainable housing, as many climate change adaptation opportunities can be combined with climate change mitigation opportunities. Examples include the use of low embodied energy adobe blocks as a means of reducing the carbon footprint of a building, while providing passive cooling and heating potential by proper use of thermal mass. Or the use of other passive ventilation methods which both reduce the need for energy consumption (to power fans for instance) to achieve comfort, while building in a home's latent ability to adjust to increasing temperatures over time. These are some of the many examples of the WIN-WIN strategies that must be understood and optimized in low cost sustainable housing design and construction. The same concepts of stacking functions that were discussed in Sections 4.2.3 and 4.2.4 are applicable in the context of optimizing the WIN-WIN synergies of climate change mitigation and adaptation for housing. We must choose

techniques which provide both mitigation and adaptation while reducing inputs as much as is feasible.

Generally, passive and low embodied energy systems which provide comfort and protection from climate stresses stack the functions of climate change mitigation and adaptation.

4.4.2 Implications for Employment of Low Skilled, Under Educated Labour for the Alleviation of Poverty (3rd WIN)

The third function in a WIN-WIN-WIN strategy is to improve the human condition. This can be in the form of health and safety, improved sanitation, education, employment and social networking. If properly conceived the production of housing can be used as a platform to employ and train workers and unite communities.

Paul Polak in his book “Out of Poverty” contends that there is a huge opportunity to increase household income in the developing world when simple, low cost technologies are placed in the hands of the local population and they are enabled to use them as a means of conducting business. If sustainable practices like low cost rainwater catchment systems that provide drinking water and irrigation for cash crops can become an enterprise for poor people to manufacture and sell, it may create a pathway out of extreme poverty. The production of low cost housing could become a powerful platform to foster income producing skills when education and skill development is integrated with construction projects. This not only makes the people involved more enrolled in the project, but it also can increase opportunities to network within their communities, increasing alliances. This can lead to numerous improvements in quality of life.

Some examples of WIN-WIN-WIN strategies in low cost sustainable housing for climate change mitigation, adaptation and social benefit:

- Use of photovoltaic technology to purify and distribute clean water
- Utilize human and animal waste to generate bio-gas that can be used for cooking, water heating and space heating.
- Provide for diverse uses within a housing development so as to keep people from having to travel to work or shop.

- Design of passive heated or cooled climate resistant housing with locally produced low embodied energy materials
- Construction and distribution of rain harvesting technologies from locally available materials
- Construction of shade structures which support food producing vegetation

Housing sector stakeholders should explore, in great detail, the various synergies or WIN-WIN-WIN opportunities that are available in low cost sustainable housing. They are various and numerous, and usually specific to the local environments, economies and vulnerabilities of the regions in which projects are to be implemented.

4.4.3 Integrated Urban Sustainability Planning

The concepts described above of WIN-WIN-WIN opportunities and the stacking of functions in design of low cost sustainable housing, must be applied in the larger context of integrated sustainable urban planning. Around the world the predominant formula for Integrated Urban Sustainability Planning, has become mixed use developments. In these developments, less transportation of people and goods is needed as they are all located in the same relative areas and utility grids are more efficient.

Historically, in many American cities, quite the reverse has been the trend. Suburban sprawl has taken the residential areas a distance from other land uses requiring huge networks of infrastructure and roads to be built. This style of planning increases net emissions of greenhouse gases and interrupts important social networks. As deeper understanding of sustainability and knowledge of the dangers of climate change grows around the world, it has become increasingly important for planners to consider every aspect of energy efficiency, from buildings to transportation to infrastructure.

Sustainable urban planning requires planners to utilize the most efficient land use design possible that will place people in close proximity to their work and places they shop and socialize. Micro-industries can be better supported within sustainable urban plans, improving the local economy and quality of life for the inhabitants.

There are some extraordinary examples of high quality sustainable urban planning in European cities. For example the Swedish city of Malmo, recently won an award from UN-HABITAT for its achievements in re-developing a previously abandoned industrial sector into a model of zero energy, sustainable design. The Western Harbour district of Malmo utilizes numerous sustainability planning examples including, public open space, intertwined residential and commercial spaces, highly energy efficient mixed use buildings, 100% renewable energy supply, and advanced waste management which produces biogas for public transportation. Although the Swedish economy and lifestyle may differ significantly from those of most developing countries, important principles and ideas can be used from this and other examples to improve the overall effectiveness of low cost sustainable housing within urban areas.

Although informal developments in developing countries (shanty towns or slums) represent in many ways what to avoid in urban development, most notably lack of basic water, sanitation and safety, these settlements sometimes contain some very important social network aspects which can be emulated in improved urban planning.

As John Turner illustrates in his book “Housing by People”, informal settlements in the world inherently embody the planning principles that western planners are now espousing (Turner, 1976). In those establishments all the functions needed in daily life are intertwined. When people are forcibly displaced from this structure, everything in their lives becomes inherently more difficult.

Sustainable urban planning that includes low cost sustainable housing should be careful to build upon the natural networking and spatial relationships that demonstrate to serve the local people in existing settlements, while improving the basic services, energy conservation and climate adaptive capacity of the population while improving the local economy and quality of life for the inhabitants.

To create more sustainable communities the focus has to be on how to localize functions and minimise the environmental and social costs of distribution, transportation and land development. If all the functions of the cities occur in closer proximity to housing, the amount of infrastructure needed is reduced significantly. If more renewable sources are used for water and energy at the source of where they are collected, even less infrastructure is needed. Overall the multiple benefits

associated with limiting greenhouse gas emissions, adapting to climate stresses, alleviating poverty and improving social well being can and should be considered in an integrated design for communities utilising many of the principles discussed in this Scoping Paper in the context of low cost sustainable housing.

5. Conclusions

In many ways the increasing needs of people for quality housing, poverty alleviation and the increasing pressures of climate change offer the world an exceptional opportunity to advance sustainable practices in an integrated way. At the core of this global effort can be the development of low cost sustainable housing. The special conditions in developing nations offer numerous challenges and opportunities to promote sustainable development through housing policy. The need for low cost sustainable housing in developing nations is a microcosm of the greater sustainable development challenge which is faced by all nations.

5.1 Key Findings

- Low cost sustainable housing is being implemented in developing countries to improve quality of life, reduce greenhouse gas emissions and provide protection from adverse climate change impacts, but capacity to coordinate and advance these efforts are limited or inconsistent .
- Advanced standards, guidelines, design tools and life cycle assessment tools, which are available in developed nations can be utilised to a limited degree in developing nations. International efforts should be increased to adapt existing tools, standards and guidelines for increased availability and usefulness in developing nations, especially for developing building energy codes and databases of embodied energy in building materials.
- International efforts to increase and improve low cost sustainable housing for developing nations have demonstrated some success, especially when local stakeholders are integrated into the process early and through completion.
- The Clean Development Mechanism (CDM) under the Kyoto Protocol has been, thus far, ineffective at supporting low cost sustainable housing in developing nations. There is however, growing awareness of this shortcoming of the CDM, and efforts are increasing to provide improved access to carbon financing for building sector projects. Significant reformation of the CDM and innovation amongst CDM developers is needed to make

carbon financing a viable mechanism for housing projects. Access to the CDM requires quantifiable and verifiable reductions in emissions which are additional to business as usual activities. It is often technically or economically infeasible to demonstrate this for small scale housing projects.

- In order to mitigate climate change by reducing energy consumption and greenhouse gas emissions attributable to housing, regionally appropriate housing design which optimises bio-climatic design principles is needed. This can be enhanced through the use of advanced energy modelling software.
- It is important to understand that in most cases, the life cycle climate impact of a home is predominantly in the energy consumption required to heat, light and cool the building. The embodied energy of the building materials has a much lesser climate impact over the life cycle of the dwelling.
- There are numerous proven techniques that are passive or low energy, low tech and affordable to maintain comfort within a dwelling while minimising energy consumption. These include: passive solar heating, thermal mass, natural ventilation, evaporative cooling, other passive cooling techniques, high performance building envelopes and energy efficient mechanical systems. All of the above should be optimised in a housing design based on climatic data and human comfort expectations.
- The use of low cost, local and low embodied energy materials are an important aspect of sustainable construction, and can improve the environmental life cycle assessment of a dwelling, while supporting local economic development, self help indigenous methods and reducing environmental impacts.
- On-site renewable energy technologies can reduce greenhouse gas emissions, improve access to basic energy needs, such as lighting or hot water, and increase adaptive capacity. Costs and limited technological knowledge can limit the effectiveness of these technologies for the least

advantaged. Renewable energy remains a critical component for sustainable housing in terms of climate change mitigation and adaptation.

- Housing design which integrates durability and resilience planning according to the expected climate impacts specific to the region and building site, can serve to increase adaptive capacity and reduce damage risks from climate change. Indigenous methods can serve as examples of climate resilient, low cost and sustainable housing options.
- Water and food scarcity is expected increase in many regions due to climate change. Sustainable housing design which utilises rain water catchment, waste-water (greywater) re-use and intelligent landscaping for water conservation and household gardening can serve to reduce the climate risks and improve adaptive capacity at low cost.
- Sustainable housing design with integrated living structures can also serve to increase energy efficiency and adaptive capacity by increasing passive cooling opportunities, access to biomass based fuels and protection from winds and extreme weather. Examples are vegetative roofs, vegetative wind breaks and climbing vines on trellises to shade buildings.
- Regionally appropriate housing design which integrates and optimises synergistic (WIN-WIN-WIN) opportunities to address climate change and improve the human condition should be carefully crafted in ways which are appropriate to the location and the occupants, while encouraging indigenous stakeholder input and ownership as a core design principle. These designs must also be integrated with sustainable urban planning to optimise access to employment, social activities, transportation and recreation.
- Standardised guidelines by region will be very useful to the replication and advancement of efforts to improve low cost sustainable housing and access to it. Local indigenous know-how and state of the art design optimisation tools should be jointly employed to develop proto-type plans and model homes that are attractive to and can be easily replicated by the local population.

Prototype plans must be technically simple and accessible to illiterate peoples, be optimized according to regional climatic conditions utilizing passive, low energy design characteristics, be influenced by advanced energy efficiency standards, codes and guidelines from regions or nations with well established research and implementation experience, and utilize state of the art energy modelling and life cycle assessment tools to provide quantifiable and measurable results which can be verified in the field.

5.2 Recommendations and ways forward

This Scoping Paper has set out to overview the vast and complicated set of issues which pertain to the development of sustainable housing, and the numerous tools, policies and best practices which can enhance efforts. There are some important issues that housing sector stakeholders can act upon to improve the success of low cost sustainable housing around the world.

- Develop partnerships with existing LCA/LCI key players to develop LCI data in regions where it does not exist.
- Develop initiatives with CDM developers, UNEP, SBCI, Designated Operational Entities and the CDM Executive Board to develop and gain approval of new methodologies that improve access to carbon financing for low cost sustainable housing projects.
- Improve integration of climate mitigation and adaptation aspects of low cost sustainable housing – at a the level of building regulations (on the ground) and at an institutional level
- Develop partnerships with international aid organisations to develop stakeholder centric low cost sustainable housing initiatives.
- Work with international trade organisations to improve access in developing regions to standardised energy efficient building and household products.
- Promote educational programmes in developing countries to increase knowledge on sustainable building practices and LCA thinking.

- Develop a comprehensive review of disaster resistant AND low cost-sustainable building techniques and materials, focussing on indigenous methods (such as cyclone resistant housing traditions in the Asia-Pacific region).
- Produce a detailed review of existing relevant building energy codes, guidelines and standards to assess which can serve HOUSING SECTOR STAKEHOLDERS in developing comprehensive policies to promote climate change mitigation in low cost sustainable housing in regionally appropriate designs.
- Produce a detailed review of existing building energy modelling software tools which can be utilised in specified developing regions to quantify energy conservation achievements within regionally appropriate housing designs
- Produce a detailed review of existing LCA tools and LCI databases which can be utilised in developing regions to quantify the embodied energy of specific building materials and home designs.
- Develop easily accessible prototype plans by region which comprehensively address local stakeholder preferences, energy conservation, climate adaptive capacity and social benefits.
- Work to integrate WIN-WIN-WIN synergies throughout the entirety of UN-HABITAT practices and initiatives.

6. References

- Acker, R.H., Kammen, D.M., The quiet (energy) revolution. Analysing the dissemination of photovoltaic power systems in Kenya. *Energy Policy*, Vol. 24, No. 1, 1996, pp. 81-111.
- Bertoldi, P., Rezessy, S., Urge-Vorsatz, D., Tradable certificates for energy saving: Opportunities, challenges, and prospects for integration with other market instruments in the energy sector. *Energy & Environment*, 16(6), 2005, pp. 959-992.
- Brown, G.Z., DeKay, M., Sun, Wind & Light: Architecture Design Strategies. John Wiley & Sons, Inc., 2001.
- Cheng, C., Pouffary, S., Svenningsen, N., Callaway, M., The Kyoto Protocol, The Clean Development Mechanism and the Building and Construction Sector – A Report for the UNEP Sustainable Buildings and Construction initiative, United Nations Environment Programme, Paris, France, 2008.
- Demirbas, A. H., Demirbas, I., Importance of rural bioenergy for developing countries. *Energy Conservation and Management*, 48, 2007, pp. 2386-2398.
- Easterly, W., Pfutze, T, Where Does the Money Go? Best and Worst Practices in Foreign Aid. *Journal of Economic Perspectives*, Vol. 22, No. 2, 2008.
- Fayaz, R., Kari, B.M., Comparison of energy conservation building codes of Iran, Turkey, Germany, China, ISO 9164 and EN 832. *Applied Energy*, 86, 2009, pp. 1949-1955.
- FGEF, Environment and energy savings in the building sector in China, 2003.
www.ffem.net
- GEF, Investing in Energy Efficiency: The GEF experience. 2009, www.theGEF.org
- GEF, Investing in Renewable Energy: The GEF Experience. 2009,
www.theGEF.org
- Goebel, A., Sustainable urban development? Low cost housing challenges in South Africa. *Habitat International*, 31, 2007, pp. 291-302.
- Gould, J. & Nissen-Petersen, E., Rainwater Catchment Systems for Domestic Supply. Intermediate Technology Publication, Warwickshire, 2006.
- Grigololetti, G., Sattler, M.A., Morello, A., Analysis of the thermal behaviour of a low cost, single-family, more sustainable house in Porto Alegre, Brazil. *Energy and Buildings*, 40, 2008, pp. 1961-1971
- Gustavsson, L., Sathre, R., Variability in energy and carbon dioxide balances of

- wood and concrete building materials. *Building and Environment*, 41, 2006, pp. 940-951.
- Haapio, A., Viitaniemi, P., A critical review of building environmental assessment tools. *Environmental Impact Assessment Review*, 28, 2008, pp. 469-482.
- Haapio, A., Viitaniemi, P., Environmental effects of structural solutions and building materials to a building. *Environmental Impact Assessment Review*, 28, 2008, pp. 587-600.
- Hansen, J., Sato, M., Kharecha, P., Beerling, D., Berner, R., Masson-Delmotte, V., Pagini, M., Raymo, M., Royer, D., Zachos, J., Target Atmospheric CO₂: Where Should Humanity Aim? *The Open Atmospheric Science Journal*, 2008, Vol. 2, pp. 217-231.
- Hertwich, E.G., Life Cycle Approaches to Sustainable Consumption: A Critical Review. *Environmental Science and Technology*, Vol. 39, No. 13, 2005, pp. 4673-4684.
- Hessami, M., Christensen, S., Gani, R., Anaerobic Digestion of Household Organic Waste to Produce Biogas. WREC, 1996.
- <http://are.berkeley.edu/courses/ARE251/2004/papers/Thorbecke.pdf>
- <http://practicalaction.org/reducing-vulnerability/docs/ia1/seminar-dec-2009/posters/esrc-poster-3-reset.pdf>
- <http://undp.org.pk/undp-wins-accolades-for-its-energy-efficient-low-cost-housing-solution-the-benazir-model.html>
- <http://stats.oecd.org/index.aspx>
- <http://www.oecd.org/dataoecd/18/8/44187916.pdf>
- <http://www.oecd.org/dataoecd/32/31/44275379.pdf>.
- http://www.oecd.org/document/20/0,3343,en_2649_34487_44221716_1_1_1_1,00.html
- IEA (International Energy Agency), Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings. 2008 OECD/IEA, Paris.
- Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: Synthesis Report. [online] http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf
- Janssen, J., Building with Bamboo. Intermediate Technology Publications, London, 1995.
- Korner, I., Saborit-Sanchez, I., Aguilera-Corrales, Y., Proposal for the integration of

- decentralised composting of the organic fraction of municipal solid waste into the waste management system of Cuba. *Waste Management*, 28, 2008, pp. 64-72.
- Kumar, R., Kaushik, S.C., Performance evaluation of green roof and shading for thermal protection of buildings. *Building and Environment*, 40, 2005, pp. 1505-1511.
- La Roche, P., Ramirez, I., Brown, K., Whitsett, K., Wehinger, K., Carranza, M., Lum, L., Reed, S., A Very Low Cost Sustainable Housing Prototype for Tijuana, Mexico. The 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, 6-8 September, 2006.
- Lancaster, B., *Rainwater Harvesting for Drylands Volume 1*. Rainsource Press, Tucson, AZ, 2006.
- Lancaster, B., *Rainwater Harvesting for Drylands and Beyond Volume 2*. Rainsource Press, Tucson, AZ, 2008.
- Langniss, O., Ince, D., Solar Water Heating: A Viable Industry in Developing Countries. *Refocus*, May/June, 2004, pp. 18-21.
- Lee, W.L. & Chen, Hua, Benchmarking Hong Kong and China energy codes for residential buildings. *Energy and Buildings*, 40, 2008, pp.1628-1636.
- Levine, M., D. Üрге-Vorsatz, K. Blok, L. Geng, D. Harvey, S. Lang, G. Levermore, A. Mongameli Mehlwana, S. Mirasgedis, A. Novikova, J. Rilling, H. Yoshino, 2007: Residential and commercial buildings. In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Li, J., *Climate resilient urban infrastructure in China – Insights into the building sector*. IDDRI, 2009, Paris.
- Li, J., Colombier, M., Barbier, C., *Shaping Climate Policy in Urban Infrastructure: An Insight into the Building Sector in China*. IDDRI SciencesPo., 2009.
www.iddri.org
- Liang, J., Li, B., Wu, Y., Yao, R., An investigation of the existing situation and trends in building energy efficiency management in China. *Energy and Buildings*, 39, 2007, pp. 1098-1106.

- Liberian Ministry of Agriculture, A cross-sectoral strategy for the Government of Liberia. 2008.
- Losada, H., Bennett, R., Soriano, R., Vieyra, J., Cortes, J., Urban Agriculture in Mexico City : Functions Provided by the Use of Space for Dairy Based Livelihoods. Cities, Vol. 17, No. 6, 2000, pp. 419-431.
- Ludwig A., Branched Drain Greywater Systems. Oasis Design, Santa Barbara, CA, 2000.
- Ludwig, A., Builder's Greywater Guide. Oasis Design, Santa Barbara, CA, 1995.
- Ludwig, A., Create an Oasis with Greywater. Oasis Design, Santa Barbara, CA, 1994.
- Ludwig, A., Water Storage tanks, cisterns, aquifers and ponds. Oasis Design, Santa Barbara, CA, 2005.
- Mazria, E., The Passive Solar Energy Book. Rodale Press, 1979.
- McKinsey and Company, Reducing U.S. Greenhouse Gas Emissions: How Much and At What Cost?, 2007.
http://www.mckinsey.com/client-service/ccsi/pdf/US_ghg_final_report.pdf
- Mechell, L., Kniffen, B., Lesikar, B., Kingman, D., Jaber, F., Alexander, R., Clayton, B., Rainwater Harvesting: System Planning. Texas Agrilife Extension Service. College Station, TX. Draft version, September 2009.
- Mills, E., Inter-comparison of North American residential energy analysis tools. Energy and Buildings, 36, 2004, pp. 865-880.
- Mollison, B., Permaculture: A Designers' Manual. Tagari Publication, Tyalgum, Australia, 1988.
- Ni, J. Q., Naveau, H., Nyns, E. J., Biogas: exploitation of a renewable energy in Latin America. Renewable Energy, Vol. 3, No. 6/7, 1993, pp. 763-779.
- Ortiz, O., Castells, F., Sonnemann, G., Sustainability in the construction industry: A review of recent developments based on LCA. Construction and Building Materials, 23, 2009, pp. 28-39.
- Parker, D., Very low energy homes in the United States: Perspectives on performance from measured data. Energy and Buildings (2009), doi:10.1016/j.enbuild.2008.11.017
- Polak, P., Out of Poverty. Berrett Koehler Publishers, San Francisco, 2008.
- Rakoto-Joseph, O., Garde, F., David, M., Adelard, L., Randriamanantany, Z.A.,

- Development of climate zones and passive solar design in Madagascar. Energy Conservation and Management, 50, 2009, pp. 1004-1010.
- Serageldin, Ismail The Architecture of Empowerment London: Academy Editions 1997
- Shukla, A., Tiwari, G.N., Sodha, M.S., embodied energy analysis of adobe house. Renewable Energy, 34, 2009, pp. 755-761.
- Turner, J. F.C., Housing By People. Marion Boyers, London, 1976.
- UNCHS (Habitat), Building Codes and Regulations in Developing Countries, 1980, Nairobi.
- UNCHS (Habitat), Case Studies on Measures for Energy Efficient Shelter and Infrastructure, 1986, Nairobi.
- UNCHS (Habitat), Earth Construction Technology. 1986, Nairobi.
- UNCHS (Habitat), The use of selected indigenous building materials with potential for wide application in developing countries. 1985, Nairobi.
- UNFCCC, Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries, 2008, Bonn.
- UNFCCC, COP 15, CMP 5 Draft Text, Further guidance relating to the clean development mechanism, Paragraph 12.d. 10 December, 2009.
- UNFPA, The State of World Population, 2009, New York.
- UN/ISDR, Indigenous Knowledge for Disaster Risk Reduction: Good practices and Lessons Learned from experiences in the Asia-Pacific Region. 2008, Bangkok.
- Urge-Vorsatz, D., Koeppel, S., Mirasgedis, S., Appraisal of policy instruments for reducing buildings' CO2 emissions. Building Research and Information, 35 (4), 2007, pp. 458-477.
- Urge-Vorsatz, D. & Novikova, A., Potentials and costs of carbon dioxide mitigation in the world's buildings. Energy Policy, Vol. 36, 2008, pp. 642-661.
- USGBC, New Construction & Major Renovation, Version 2.2, Reference Guide, Third Edition, 2007. US Green Building Council, Washington DC.
- USGBC, LEED for Homes Reference Guide, First Edition, 2008. US Green Building Council, Washington DC.
- Utama, A., Gheewala, S.H., Influence of material selection on energy demand in residential houses. Materials and Design, 30, 2009, pp. 2173-2180.
- Vijay, V.K., Prasad, R., Singh, J.P., Sorayan, V.P.S., A Case for Biogas Energy

Application for Rural Industries in India. WREC, 1996.

Werlin, H., Corruption and foreign aid in Africa. Orbi, Vol. 49, Issue 3, 2005, pp. 517-527.

Online references and resources

www.athenasmi.org

www.akvo.org

www.arcsa.org

www.bath.ac.uk/mech-eng/sert/embodied

www.codeofchina.com

www.ecoinvent.ch

www.ecotect.com

www.energystar.gov/index.cfm?c=new_homes.hm_index

www.epa.gov/hiri/mitigation/coolroofs.htm

www.imf.org/external/about.htm

www.gabi-software.com

www.gefweb.org

www.usgbc.org/Docs/News/CGI%200909.pdf

www.worldgbc.org

www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm

www.iso.org

www.palosantodesigns.com

www.pre.nl/simapro

www.sgppakistan.org

www.unep.org/sbci/index

www.unep.org/DOCUMENTS.MULTILINGUAL/DEFAULT.asp?documentID=52

www.worldbank.org

www.worldhandsproject.org