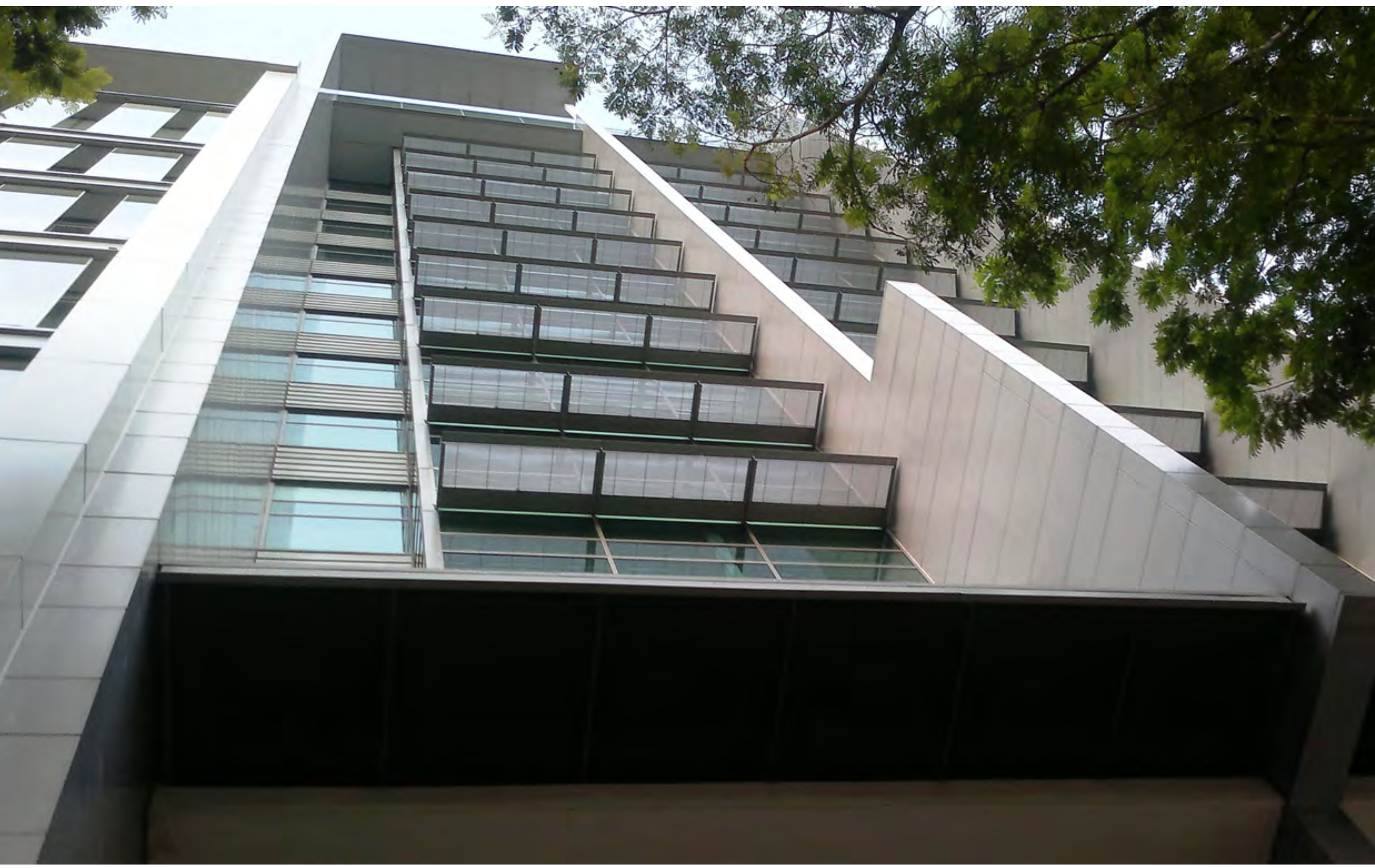
TNA Guidebook Series

Technologies for Climate Change Mitigation

– Building Sector –



UNEP RISØ CENTRE

ENERGY, CLIMATE AND SUSTAINABLE DEVELOPMENT

Technologies for Climate Change Mitigation

– Building Sector –

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Preface

Buildings are responsible for about one-third of global greenhouse gas emissions, making buildings the single largest contributor to global greenhouse gas (GHG) emissions. An average person spends about 90 per cent of their time inside buildings.

This presents the building sector with the challenge of reducing GHG emissions, while maintaining, if not enhancing, the quality of services to building occupants. Furthermore, the building sector typically contributes 5 to 15 per cent of a country's GDP on average, and provides 5–10 per cent of employment at the national level. Mitigating climate change in the building sector also means providing opportunities for a green economy and more green jobs.

The building sector offers vast opportunities for reducing GHG emissions, while strengthening sustainable development, within and across nations. This guidebook provides a detailed description of mitigation technologies and practices in the building sector. It aims to contribute necessary technical knowledge and information for countries to carry out Technology Needs Assessments and develop Technology Action Plans that support climate change mitigation and sustainable development.

This publication is part of a technical guidebook series produced by the UNEP Risø Centre on Energy, Climate and Sustainable Development (URC) as part of a larger Technology Needs Assessment project. Its production was coordinated by Dr Jorge Rogat and authored by Dr Wynn Chi-Nguyen Cam, a passionate architect and researcher on sustainable built environment.

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Executive Summary

Addressing global climate change requires concerted efforts from all nations – both developed and developing. These efforts include assessing, planning and implementing relevant technologies and best practices, in a cost-effective manner to unleash mitigation and adaptation potentials in all sectors. In this context, the Global Environment Facility funds the Technology Needs Assessment (TNA) programme, which is being implemented in 36 developing countries by the United Nations Environment Programme (UNEP) and UNEP Risø Centre. The objectives of TNA are to examine the contribution that different technologies can make to national climate change mitigation and adaption goals, and prioritise these technologies based on national development priorities and plans. This guidebook is designed to assist participating countries to carry out Technology Needs Assessments in the building sector. Based on the TNA, the Technology Action Plan (TAP) can be developed to identify barriers to the acquisition, deployment and diffusion of priority technologies. Practical actions can then be determined to overcome these barriers, in order to realise the building sector's mitigation potential.

The guidebook's primary audience group consists of national TNA teams, which comprise a broad range of stakeholders from government institutions, NGOs and the private sector, including professionals from the building industry. It is intended to be a source of information and technical knowledge on climate change mitigation in the building sector for these stakeholders, especially those in countries and regions, where accessibility of such information is limited.

The building sector's large contribution to global greenhouse gas (GHG) emissions has been widely acknowledged. The major causes of these large contribution are the extensive use of fossil fuel-based energy in buildings for thermal comfort, lighting, water heating, electrical equipment and appliances, as well as in the production of construction materials.

Mitigating the building sector's GHG emissions requires integrated innovative solutions and sustainable technologies during design, construction, operation, and demolition of buildings. This is the hardware, which must work harmoniously with the software and orgware. In TNA terminology, software refers to the processes associated with the use of the hardware, such as practices, experiences and know-how, and orgware refers to the institutional framework that is necessary for the process of the adoption and diffusion of new technology (URC TNA Team, 2012).

This guidebook puts the hardware, software and orgware into a systematic framework. This framework defines and structures the technologies and practices to mitigate climate change from the easiest and most feasible to the more sophisticated, in the context of developing countries. Furthermore, where applicable, the individual technologies and practices are discussed in terms of their ease of implementation in various regions/countries and climatic conditions. With this structure, the mitigation typologies in the building sector are clearly defined and understood in terms of operational clarity.

Over the years, many developing countries have also built up significant capacities in the area of green building technologies and practices which are highly suitable for transfer and application to neighbouring countries or other developing countries (due to contextual similarities) and require little or no modification. Therefore, the technologies and practices with possibilities for South-South transfer are highly desirable, and are described in detail in this guidebook.

Last but not least, priority is also given to technologies that address integrated applications, renovated or innovative indigenous technologies, and those that can be implemented as community sustainable building practices. As far as possible, the studied technologies and practices are applicable in both new buildings and for retrofitting existing buildings. They are also analysed in terms of what is, and what is not applicable in various localities of the world.

In brief, this guidebook aims to provide a detailed understanding of mitigation technologies and practices in the building sector, as the basis for countries to carry out TNAs and develop TAPs. These technologies and practices are studied with various considerations, including (1) setting-up supporting policies, (2) capacity building, (3) ease of creating market demand and (4) possibility for South-South transfer. These findings form a backbone for nurturing a sustainable lifestyle and behaviours of building occupants, through educational programmes and public campaigns to raise awareness. Taking such a systematic approach will put the building sector in a better position to achieve its mitigation potential, and improve the built environment for living, learning, working and playing, especially in the context of developing countries.

1. Introduction and Outline

1.1 Introduction

Significance of the building sector

Buildings provide the foundation for our daily activities. Buildings are associated with every aspect of a country's development, including housing, education, healthcare, workplaces, community services, infrastructure and communications.

Figure 1.1.1: Buildings associated with living, learning, working and playing

We spend most of our time inside or in association with buildings. For example, on average, Americans spend about 90% of their time indoors (US EPA, 2009). Therefore, buildings greatly impact every aspect of our lives: social, economic and environmental.

Social aspect: buildings impact occupants' health, quality of life, and to some extent, influence occupants' perception and interaction with the surrounding natural environment. In many developing countries, poor indoor air quality caused by combusted biomass and poor ventilation, causes serious illness such as pneumonia and tuberculosis, and premature death (UNEP, 2011). At a macro level, a cluster of buildings define a neighbourhood, and have an influence on the crime rate, social inter-activity and community development.

Economic aspect: the building sector has been growing for the past decades to meet the demands of population expansion, rural-urban migration and economic development. The building sector typically contributes 5-15% of a country's GDP, and provides 5-10% of employment at a national level (UNEP SBCI, 2007). At a more micro level, good building design and good indoor environmental quality have proven to contribute to better productivity. In purely economic terms, return on investment can be recouped far faster through better worker productivity than through energy savings alone.

Environmental aspect: the building sector is the single largest contributor to global greenhouse gas (GHG) emissions (UNEP, 2011) and is estimated to account for a third of all energy-related CO_2 emissions globally (Price et al., 2006).The building sector is also material intensive, accounting for the largest share of natural resource use globally. Buildings, through urbanisation and urban sprawl, result in the loss of productive land and threats to biodiversity. Solid and liquid wastes discharged from buildings, in many regions, cause pollution and affects public health.

Mitigation in the building sector: potential and challenges

As the major contributor to GHG emissions, the building sector also presents the "largest potential for delivering long-term, significant and cost-effective greenhouse gas emission reductions" (UNEP SBCI, 2009). It is estimated that energy use in buildings can be reduced by 60% by 2050, if actions to transform the sector through energy efficiency start immediately. The amount of energy reduction is equivalent to the total energy consumed by both the transport and industrial sectors in 2009 (WBCSD, 2009).

There are also many barriers to realising this potential. According to estimates by the Intergovernmental Panel on Climate Change (IPCC), the number of barriers in the building sector is higher than in any other sector (Levine et al., 2007). This guidebook identifies and categorises the key barriers into four groups. They are:

1. Lack of awareness and access to technical knowledge
2. Segmentation and fragmentation of the building sector
3. Perceived financial disincentive
4. Consumerism aspiration and rebound effect.

This book addresses the first group of barriers and gives strong consideration to the second, third and fourth groups of barriers. Overcoming the first group of barriers is believed to be the fundamental step to realise mitigation potential from the building sector in developing countries.

Realising mitigation potentials in the sustainable development context

Jonas and Gibbs (2009) observe that "Carbon control would seem to introduce a new set of values into state regulation and this might open up possibilities for challenging mainstream modes of urban and regional development in a manner not possible under sustainable development." Without the over arching goal of sustainable development, climate change mitigation will lose its enthusiasts and supporters in the long-term (Cam, 2011).

In the building sector, approaches to climate change mitigation must be in harmony with the wider sustainable development context. For this reason, the mitigation technologies and practices in chapters 3 and 4, outline the opportunities they present to leverage the building sector's significant impacts to social and economic development, to achieve a comprehensive approach.

Turning challenges into opportunities

This book aspires to turn the challenges of climate change mitigation into opportunities for the building sector, especially in developing countries. It does so, by structuring and presenting the mitigation technologies and practices so they are in line with sustainable development objectives. Their implementation approaches and strategies are extended beyond technical realms, in order to maximise reciprocal relationships with social and economic aspects, and quality of life improvement.

In this way, mitigation technologies and practices, instead of being viewed as additional requirements to business-as-usual practice in the building sector, become opportunities for overall sustainable development of countries, regions, cities, and communities. In other words, implementing mitigation technologies and practices should be equal to strengthening social and economic development.

1.2 Book outline

Chapter 2 summarises key findings on the contribution of the building sector towards GHG emissions. The main contributor of global GHG emissions has been identified by many international organisations to be the extensive use of fossil fuel-based energy in buildings for thermal comfort, lighting, water heating, electrical equipments and appliances, as well as in the production of construction materials. GHG emissions, however, vary according to the country's stage of development, building types, number of new buildings versus existing buildings, and different stages of a building's life cycle. The findings on barriers to mitigation efforts from the building sector are also summarised.

Chapter 3 defines and structures technologies and practices as possible GHG mitigation solutions, from the most feasible to the more sophisticated, with a focus on the context of developing countries. Using this structure, the mitigation typologies can be defined in a framework with operational clarity. The framework consists of one prerequisite and seven broad typologies. Each typology comprises a number of relevant technologies and practices. The typologies are as follows:

Prerequisite:	Passive solar design
Typology 1:	Advanced passive solar design
Typology 2:	Technologies that enhance passive solar design performance
Typology 3:	Active design
Typology 4:	Low carbon and carbon sinks
Typology 5:	Onsite renewable energy generation
Typology 6:	Monitoring and occupants' feedback loop
Typology 7:	Beyond individual buildings.

Chapter 4 provides detailed analyses of the individual technologies and practices under each of the seven mitigation typologies. The detailed study of each mitigation technology and practice comprises two components: background information and detailed analyses. The background information includes:

1. Definition, description and characteristics
2. Stage of development in terms of present status (proven or under test-bedding) and potential improvement through research and development
3. Contextual (climatic and spatial) requirements for application.

The detailed analyses include:

1. Implementation status in terms of present market penetration; future market potential in different regions/countries; and future market potential
2. Feasibility for implementation, in terms of the requirements for certain institutional/organisational settings, and capacity building
3. Contributions to social, economic and environmental development in different regions/countries
4. Financial requirements and costs (e.g., investment costs, operational and maintenance costs, etc.) wherever information is available
5. Case studies from various regions/countries, covering success stories and possibilities for South-South information transfers.

Chapter 5, based on the detailed analyses in Chapter 4, makes recommendations for the implementation of the mitigation technologies and practices. These recommendations cover:

1. Practical guidance on prioritising mitigation technologies and practices at a national level
2. Settings, stakeholders and strategies to implement the technologies and practices
3. Practical steps to implement, upscale the adoption, transfer and further develop the technologies and practices.

Although the recommendations are discussed in the form of principles, it is emphasised that there is a need to understand and contextualise prioritisation and implementation to suit the country or local conditions. These conditions include the geographic setting; state of economic development; status and trend of urbanisation; quality of existing building stock; strength of existing industries within and related to the building sector; availability of existing workforce and experts; social and behaviour norms; and existing indigenous technologies and practices with mitigation potential.

Chapter 6 emphasises that mitigation technologies and practices must be applied appropriately. They must take into account the country's context and be in line with other sustainable development strategies. The key goal is to overcome the barriers to the mitigation potential in the building sector and make mitigation typologies part and parcel of the comprehensive sustainable development of the nation.

Additional sources of information on each technology and practice (as described in Chapter 5), are provided in the Appendix III. The information includes initial lists of technology providers and global/regional/national organisations that provide expertise on technologies and practices. These lists aim to serve only as examples and a starting point for public contributions to the more comprehensive and updated information from Climate Techwiki, which is an online platform on climate change mitigation and adaptation technologies, created by UNEP and UNDP.

In the context of the projected trend of higher GHG emissions from the building sector in developing countries, the implementation of Technology Needs Assessments and development of Technology Action Plans are timely and important ways to address this trend. This book aims to contribute to this endeavour in a meaningful manner, i.e., to support the building sector to reduce GHG emissions while contributing to higher quality of life, economic growth, job creation and sustainable community building.

2. Summary of Key Findings on the Contribution of the Building Sector Towards GHG Emissions

2.1 Status and trends at the global scale

Global statistics

The Fourth Assessment Report of the IPCC, the Stern Review Report on the Economics of Climate Change, and the European Commission (2007) indicates the target to keep global warming to 2°C above pre-industrial levels, in order to potentially avoid some of the worst climate change impacts. Achieving this target requires global emissions to peak by 2015-2020, and to decline rapidly to 2050 and beyond. This translates to a global emissions reduction of at least 50% of 1990 levels, from approximately 40GtCO_2-e/year to 20GtCO_2-e/year.

In the building sector, it has been widely understood that fossil-fuel based energy consumed by buildings and by delivering new buildings is the largest contributor to greenhouse gas emissions (GHG). Globally, the building sector accounts for about one-third of global GHG emissions by consuming more than 40 percent of global energy used (Levine et al., 2007). This is about 8.6 million metric tons CO_2-ein 2004, according to the Intergovernmental Panel on Climate Change (IPCC). The International Energy Agency (IEA) and the Organisation for Economic Co-operation and Development (OECD) project that by 2050, energy demand in the building sector will increase by 60%, which is a larger projected increase than is projected for the transport sector or industrial sector (IEA & OECD, 2010).

The IPCC identifies the main sources of GHG emissions associated with buildings as space heating, space cooling, water heating, artificial lighting and the use of appliances. In addition, buildings, with their use of insulation materials, and refrigeration, are also responsible for non-CO_2 GHG emissions, including halo carbons (CFCs and HCFCs) and hydro-fluorocarbons (HFCs). These gases contribute more than 15% of the 8.6 million metric tons CO_2-e, and their emission levels are projected to be constant until 2015 and then decline (Levine et al., 2007), once the policies under Montreal Protocol come into effect. UNEP's report on HFC states that "HFC emissions and their atmospheric abundances are rapidly increasing. Without intervention, HFC emissions in the future (say by 2050) could offset much of the climate benefit achieved by the Montreal Protocol" (UNEP, 2011a).

Despite the debates, most studies relating to the global GHG emission contribution of the building sector have paid great attention to the emissions resulting from energy use in the sector. Of the total energy use in buildings globally, 45% is consumed in OECD countries, 10% in economies in transition, and the balance is in developing countries (Levine et al., 2007).

Under the IPCC's high growth scenario it is estimated that the total GHG emissions from the building sector will almost double to 15.6 billion metric tons CO_2-e by 2030. In fact, from 1999 to 2004, GHG emissions from buildings' energy use increased by an average of 2.7% per annum.

Variances attributable to stages of development

It is observed that GHG emissions from buildings correlate with the stage of economic development of a country. For example, the IPCC reports that from 1971 to 2004, the largest regional increase in CO_2 emission was from developing countries in Asia, i.e., 42% from residential buildings and 30% from commercial buildings (Levine et al., 2007).

Historically, North America, Western Europe, Caucasus and Central Asia were the major contributors to GHG emissions. However, under the IPCC's high economic growth scenario, the total emissions from developing countries will surpass these regions by 2030 (UNEP SBCI, 2009). From 2004 to 2030, increases in GHG emissions will occur in developing countries and economies in transition that are developing Asia, Middle East/North Africa Latin America and sub-Saharan Africa, in that order (Levine et al., 2007). The key reason is that developing countries are projected to add 2.3 billion to the global population in the next four decades (UN DESA, 2009), and increases in population fuel urbanisation. Research from the World Bank shows that an increase of 1% of urban population correlates to a 2.2% increase in energy consumption (WBCSD, 2008).

Furthermore, these countries are experiencing high economic growth rates, adding to the pressure of rapid urbanisation. These require great numbers of buildings to address shortages of housing and other commercial buildings to cater for social, economic and other activities. For example, the World Business Council for Sustainable Development estimates that China may add as much as twice the amount of the office space in the US in the two decades starting from 2000 (WBCSD, 2009).

Construction demand, urbanisation and rising household incomes are the main factors pushing up energy demand and use in buildings, leading to a higher GHG emission contribution. In India and China in recent years there has been a noticeable shift away from traditional energy sources of biomass, agriculture waste and animal dung energy to using commercial fuels, such as LPG, kerosene and electricity. As an economy grows and infrastructure develops, electricity and gas are more accessible, especially to areas that were once rural. This accessibility stimulates the aspiration to own electrical appliances, which in turn increases energy demand. This vicious circle is reinforced by the increasing household affordability of electricity, due to higher household incomes (UNEP SBCI, 2009).

2.2 Understanding GHG emissions at building scale

Variances attributable to building types

The majority of studies and reports about the building sector's GHG emissions categorise buildings into two general types: residential and commercial. While the definition of residential buildings is as straightforward as the words suggest, commercial buildings refer to all non-domestic residential buildings, such as public, tertiary, office, municipal, etc. This common definition is used in this guidebook.

Different building types have different energy consumption patterns and thus contribution to GHG emissions. In general, residential buildings account for the majority share of total energy consumption. For example, in sub-Saharan Africa, residential buildings account for about 96% of the total building sector's energy consumption. In Europe, residential buildings consume 76% of the total building sector's energy consumption (Earth Trends, 2005).In terms of emissions growth rates, from 1971 to 2004, commercial buildings are estimated to have had 2.5% growth per annum, where as residential buildings have had a 1.7% growth rate per annum (Levine et al., 2007).

Emissions at different stages of building life cycle

GHG emissions from the building sector occur through the consumption of fossil-fuel based energy and electricity for various activities throughout a building life cycle. UNEP SBCI (2007), referencing Jones (1998), identifies energy consumption occurring during the five key activities of building life cycle, as discussed below:

Manufacturing of building materials, during which energy is used to extract raw natural resources (mining), process and manufacture them to building materials and components. Such energy is referred to as embodied energy. High embodied energy materials are those that require a greater amount of processing. Concrete, aluminium, steel, and plastic are among the highest embodied energy materials.

Transporting building materials from sources/production plants to building sites, which, in many cases, can require large amount of energy for long-distance international shipments of large quantities of heavy materials. Such energy is referred to as grey energy.

Figure 2.2.1: Energy used for construction-related transportation

Constructing the building, during which energy is used to operate construction machinery, and other activities at the construction site. This energy is referred to as induced energy.

Figure 2.2.2: Energy used to operate construction machinery

Operating the building, during which energy is used for various demands, including heating, ventilation and air conditioning, water heating, lighting and appliances. This energy is known as operation energy.

Figure 2.2.3: Energy use during building operation stage (Hong Kong)

Demolishing the building, when energy is used for demolition machinery, waste transportation, and recycling of building materials (where applicable) and so on. Such energy is known as demolition-recycling energy.

Figure 2.2.4: Building demolition

Figure 2.2.5: Sorting materials for recycling

In general, among the five types of energy consumption above, operation energy represents the largest portion of a building's whole-life-cycle energy. In GHG emission terms, a building's operation generally accounts for over 80% of their whole-life-cycle GHG emissions (UNEP SBCI, 2009). Only a small percentage of whole-life-cycle GHG emissions account for other activities, i.e., building materials manufacturing, transporting, constructing and demolishing. Therefore, reducing energy requirements during the operational stage is crucial to reduce GHG emissions from the building sector.

New buildings versus existing buildings

In general, it makes more economic sense to integrate energy efficient measures and technologies at the early design stage of buildings, compared to retrofitting these buildings for more energy efficient later. Nevertheless, due to the high number of existing buildings, especially in developed countries, a large amount of GHG emissions result from the inefficient operation of these buildings. In order to significantly reduce the sector's GHG emissions in a short time frame, retrofitting existing buildings to make them more energy efficient plays an important role.

Figure 2.2.6: Existing buildings in good condition as possible opportunities for energy efficient retrofitting (Nottingham City)

Compared to existing buildings, new buildings offer greater flexibility and opportunities for implementing energy efficiency measures at the outset. For example, in America, new residential buildings can be 30% more energy efficient than existing housing (Pew Center on Global Climate Change, 2009). In developing countries, there is significant potential to create energy efficient building stock for the future, because a large number of new buildings need to be rapidly built to adequately house a growing population of over 500 million (UNEP, 2011). This presents a huge opportunity for investment in large-scale energy efficient measures and technologies, which can be integrated into the earlier design stage for new buildings.

Figure 2.2.7: Demand for newly built housing in developing countries (Vietnam)

Nevertheless, some of the large cities in developing countries do present opportunities for retrofitting buildings to become more energy-efficient. For example, in India, it is estimated that retrofitting existing commercial buildings with cost-effective energy efficient technologies can yield energy savings of up to 25% (UNEP SBCI, 2010).

2.3 Understanding barriers to mitigation

Being the major contributor to GHG emissions, the building sector presents the "largest potential for delivering long-term, significant and cost-effective greenhouse gas emission reductions" (UNEP SBCI, 2009). Nonetheless, many barriers exist. A review of existing studies shows that there are many key barriers. This guidebook groups these barriers into the following four groups:

Lack of awareness and access to technical knowledge

This first group of barriers exists largely in developing countries, where the importance of GHG emissions and energy efficiency in buildings is a lower priority compared to many other urgent issues, such as poverty eradication, public health improvement and crime reduction. As a result, the benefits of making building energy efficient are often not recognised. Therefore, acquiring relevant technical knowledge, including low-cost yet effective technologies and good practices, is neglected.

There are also barriers to accessing knowledge and technologies in many rural regions of developing countries, due to the lack of means of communication. In urban areas, most building occupants are not aware of the energy saving potentials of the buildings they occupy, due to the lack of quantitative measurement of energy performances in buildings.

Segmentation and fragmentation of the building sector

This second group of barriers reflects the nature of the building sector, as follows:

1. Reduction potentials are divided into many small opportunities, across hundreds of millions of individual buildings (UNEP & CEU, 2007). Such small savings from large numbers of end-use units, although cumulatively create a great emission reduction, require the participation of a great number of building owners and stakeholders. This becomes a challenge.

2. At different stages in a building's life cycle, different stakeholders are involved, such as property developers, financiers, project managers, architects, civil and structure engineers, mechanical and electrical engineers, facility managers, owners, tenants, sub-tenants and so on. Each of these stakeholders plays different roles, bears different responsibilities, and has a different way of doing things. Each decision taken by each of these stakeholders has an impact on the building's emission levels over its entire lifetime. However, incentives and opportunities for coordination between stakeholders are limited, and enormous amounts of time and resources are required to carry out stakeholder coordination UNEP SBCI, 2009).

Perceived financial disincentives

The third group of barriers relates to the perceived financial disincentives of investment in energy efficient measures and technologies. UNEP & CEU (2007) highlight the following:

1. **Perception of such investment is costly and risky.** Most importantly, there is a lack of awareness about low cost energy efficient measures and technologies. This is due to the false perception that energy efficiency is costly because additional state-of-the-art technologies are required. In fact, there are low- to no-additional- cost solutions that have proven to be equally, if not more, effective than costly technologies, as shown in the following two chapters.

2. **Split economic interests among stakeholders.** This refers to the situation, where the parties who pay for energy use do not have the opportunity to make decisions about specifying energy efficient measures and technologies. For example, in America, 90% of new home buyers obtain their cooking ranges and dishwashers through their builders (Pew Center on Global Climate Change, 2009). The builders, however, may not install the most energy efficient ones, due to the uncertainty of the home buyers' acceptance of the higher house selling price due to the incremental cost of energy efficient appliances.

In addition, building owners and tenants are not always rational when it comes to choices of investing in energy efficient measures and technologies. They may use simple return-on-investment tools to calculate payback periods, without taking the possibility of future higher price of fossil-fuel energy into account. They may be more willing to take risks to avoid losses than making economic decisions based on long-term gains. As a consequence, the decisions are often made with bias towards business-as-usual, and are often reluctant to invest in energy efficient technologies and measures, due to time- and/or resource-constraints.

Consumerism, aspiration and the rebound effect

In developing countries, especially the economies in transition, greater incomes and capital gains have increased consumerism. Resource conservation is often seen as the practice of the poor, and wasteful behaviours are perceived as symbolic of being successful. Such perceptions greatly hinder the acceptance of practices that achieve lower GHG emissions in the building sector.

The investment in energy efficient technologies and measures does not always warrant the resulting low-energy consumption in reality, leading to less GHG emissions from buildings. One of the reasons is the rebound effect through occupant behaviours. This refers to the phenomenon of greater take-up rate of energy efficient technologies, equipment and appliances that then make them more cost effective and affordable. This, in turn, encourages users/occupants to buy more appliances, and make greater use of them to a level that erodes the estimated energy savings and potential emissions reductions. Some studies estimate that in America, 10% to 40% of water heater efficiency gains can be eroded by increased water heater usage (Pew Center on Global Climate Change, 2009).

Moving forwards

The contents in the coming chapters focus on addressing the first group of barriers, with consideration of the second, third and fourth groups of barriers. This approach creates a foundation with to realise materialise mitigation potentials from the building sector in developing countries.

3. Definition and Typologies of Mitigation

3.1 Definition of mitigation in the building sector

Mitigation technologies and practices

It is widely accepted that fossil-fuel based energy consumed by the building sector (from building operations and delivering new buildings) is the main source of GHG emissions. The Fourth Assessment Report of the Intergovernmental IPCC identifies the main sources of GHG emissions associated with buildings as: space heating, space cooling, water heating, artificial lighting and the use of appliances. (Levine et al., 2007).The report also identifies three categories of measures to reduce GHG emissions from buildings as follows:

1. Reducing energy consumption and embodied energy in buildings
2. Switching to low-carbon fuels including a higher share of renewable energy
3. Controlling the emissions of non-CO_2 GHG gases (Levine et al., 2007).

In addition to the above, measures to mitigate climate change in the building sector include creating opportunities for buildings to:

1. Sequester carbon, either statically through the use of carbon-trapped building materials, or continuously through the integration of greenery on the buildings and within the building site
2. Catalyse improved sustainability behaviour by building occupants and the wider community.

In this broad context, mitigation from the building sector can be defined as deploying and implementing design strategies, technologies and practices that:

1. Reduce energy demand and consumption associated with the buildings – from design, construction, hand-over, operation to renovation and end-of-life
2. Switch to low- or no-carbon fuels
3. Maximise opportunities for buildings to sequester carbon
4. Catalyse behaviour change towards sustainable lifestyles.

Systematic approach

The design strategies, technologies and practices are the hardware. The use of the hardware, including practices, experiences and know-how is the software. The feasibility for implementation and for the diffusion of new technologies, including setting up supporting policies and capacity building to train work forces, is the orgware. To be effective in large-scale mitigation of GHG emissions, all the hardware, software and orgware should be put into a systematic framework, which defines and structures the mitigation technologies from the most feasible to more sophisticated typologies.

The systematic integration of the hardware, software and orgware then forms a foundation to nurture the heartware, which refers to sustainable lifestyles and behaviours of the building occupants, through educational programmes, public campaigns to raise awareness and so on. Such a systematic approach will put the building sector in a better position to achieve its mitigation potential, and improve the living and working environment for their occupants, especially in developing countries.

Defining mitigation typologies

Using the above systematic approach and objectives, the mitigation typologies in the building sector can be defined with operational clarity. This is particularly useful in developing countries, where a Technology Needs Assessment (TNA) can be carried out to identify the most effective mitigation typologies in terms of socio-economic, contextual and temporal appropriateness.

In detail, the framework consists of eight broad mitigation typologies as follows:

1. Passive solar design
2. Advanced passive solar design
3. Technologies that enhance passive solar design performance
4. Active design
5. Low carbon and carbon sequestration
6. Onsite renewable energy generation
7. Monitoring and occupants' feedback loop
8. Beyond individual buildings.

The mitigation technologies and practices in the eight typologies, depending on their individual nature, can be deployed and implemented in newly-constructed buildings and retrofitting existing buildings.

It is noted that the mitigation typology of passive solar design is applicable to newly-constructed buildings, and should be considered at an early design stage. The design strategies are the basic principles to deliver thermal comfort among other good building environment performances to the buildings' occupants in an energy efficient manner. They do not require any mechanical equipment to run, and thus are most feasible to implement, and usually do not require additional costs. Therefore, the passive solar design mitigation typology should be considered as a prerequisite for all newly-constructed buildings. The passive solar design mitigation typology will be described in more detail in Section 3.2 and the technologies and practices from the others even mitigation typologies will be studied in Chapter 4.

Table 3.1.1 provides an overview of the technologies and practices of each of the mitigation typologies.

Table 3.1.1: Typologies of mitigation technologies and practices

No.	Mitigation typologies	Technologies and practices
Prerequisite	**Passive solar design**	Site selection
		Design responsive to the sun
		Design responsive to wind
		Use of thermal mass materials
1	**Advanced passive solar design**	Renovation and innovative use of traditional building materials and techniques
		Passive house design and technologies
2	**Technologies that enhance passive solar design performance**	Life cycle and integrated design process
		Building envelope thermal insulation
		High performance building façade systems
		Daylight harnessing technologies
3	**Active design**	Highly efficient heating, ventilation and air conditioning systems
		Efficient lighting systems
		Water efficiency technologies
4	**Low carbon and carbon sequestration**	Carbon-sequestration and low-carbon building materials and products
		Greening and building integrated greenery systems
5	**Onsite renewable energy generation**	Solar technologies
		Building integrated wind turbines
6	**Monitoring and occupants' feedback loop**	Energy management and performance improvement
		Behaviour change catalysts
7	**Beyond individual buildings**	Community based energy services
		Sustainable community design and practices.

3.2 Passive solar design – the prerequisite for newly-constructed buildings

Passive solar design includes design strategies that enable buildings to respond to the bio-climatic and geographical conditions of the building site and its immediate environment. The objectives are to reduce energy demand for thermal comfort, artificial lighting and other building environmental performance. Passive solar design strategies are often associated with low-rise, low-density buildings. However, many of these strategies are also applicable to high-rise and high-density built environments. Passive solar design strategies include:

1. **Site selection:** to facilitate comfort and a healthy lifestyle for occupants without damaging existing healthy ecosystems and biodiversity. Sites to be avoided for building development include greenfield sites; sites that are rich in biodiversity; and sites subject to flooding, landslides, and other natural disasters. Residential buildings should also avoid unabated brown field sites, and sites under constant air pollution and radon that are hazardous to occupants' health.

Figure 3.2.1: Building development without proper site selection affects biodiversity, these are often found in mountain, forest and coastal areas.

2. **Design responsive to the site conditions:** to minimise unnecessary alterations to the site. An example is levelling the site for ease of construction through a cut-and-fill method, which requires energy to transports and earth to or away from the site. Furthermore, such activities may also disrupt the natural hydrology, and negatively impact biodiversity on the site and its surroundings.

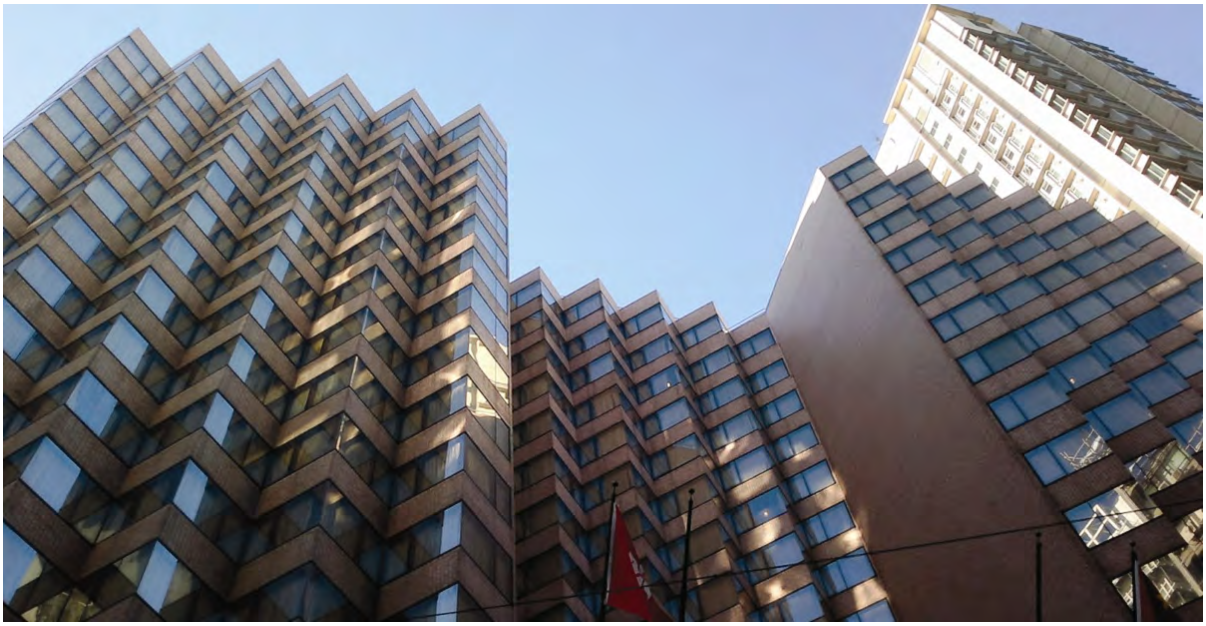
Figure 3.2.2: Responsive design to hilly terrain.

3. **Design responsive to the sun:** by orientating buildings away from facing east or especially west, in order to avoid hot afternoon sun penetrating the building envelope. Buildings in the northern hemisphere should have openings/windows facing south for solar accessibility. Likewise, buildings in the southern hemisphere should have openings/windows facing north.

Figure 3.2.3: High density housing design with no west-facing windows in the tropics

Self-shading through building massing articulation is particularly useful for buildings in the hot and arid, and hot and humid regions. For example, courtyards or windows can be well shaded from afternoon sun by other high walls/components on the west of the same building.

Figure 3.2.4: Building massing creates self-shading effect – i.e., most windows are shaded from the hot sunlight shining from the left

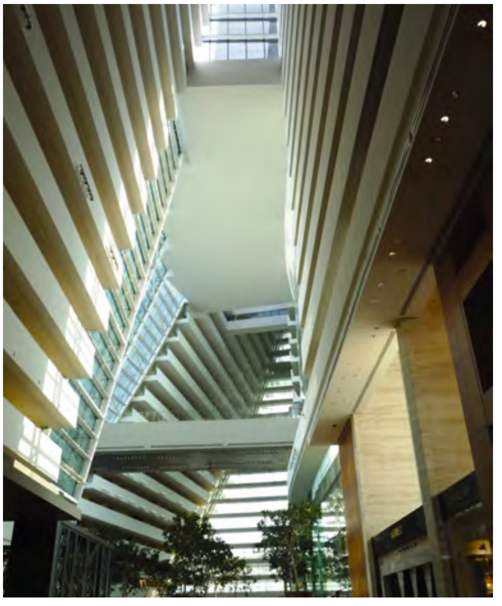


Furthermore, sun shading devices can also be designed with appropriate shapes, width, and positions, in order to further protect openings and windows from hot summer sunlight, and yet allow winter sunlight and daylight to penetrate deep into the building interior.

Figure 3.2.5: Sun shading application allowing daylight into building interior spaces.

Sun-responsive design also means maximising daylight into the building, so that energy demand for artificial light is low. This can be achieved through various design strategies, such as skylights, appropriate windows and internal courtyards. Their detailed designs, however, should address the potential heat-gain to the building interior, especially in summer months and in hot climatic regions, with strategies mentioned in the paragraphs above.

Figure 3.2.6: An example of daylight penetrating into building interior



4. **Design responsive to wind:** though designing built forms and openings that capture the predominant summer breeze and direct it to the building interior to improve natural ventilation, and block prevailing cold winter wind from entering the interior.

Figure 3.2.7: Design to improve natural ventilation in the tropics

In many instances, there are chances for combining natural ventilation and daylight accessibility to building interior spaces. Passive design should optimise these opportunities.

Figure 3.2.8: Combining natural ventilation with daylight accessibility for a house in Vietnam

5. **Use of thermal mass materials:** which absorb and store warmth and coolness to prevent large changes of indoor temperature as the outdoor temperatures vary in a large range and/or in a short time frame. Masonry, stone products and concrete have good thermal storage capacity. Their application in passive solar design include design strategies that allow the thermal mass materials (a) to be exposed to sunlight during winter days for space warming at night, and (b) to be exposed to cool summer nights for space cooling during the day.

Figure 3.2.9: Design using thermal mass in temperate climate of North America

3.3 The seven mitigation typologies

1. Advanced passive solar design

The advanced passive solar design typology can be considered as a step beyond the prerequisite of passive solar design, as described in Section 3.2. This typology includes passive house design and technologies, which take the conventional passive solar design principles as a starting point and combine them with an airtight, well-insulated building envelope, and heat recovery technologies to create buildings with very low energy requirements.

In addition, the typology recognises the potentials of traditional building materials and design, and pays attention to the significance of the role of renovation and the innovative use of traditional building materials and techniques. Thanks to a certain level of familiarity of such practices by the local residents and the availability of local materials at low (or even no) cost, these materials and practices are highly and readily applicable in many rural areas and least-developed countries. There is also great potential for South-South transfers of such materials and practices.

2. Technologies that enhance passive solar design performances

This typology reinforces the efforts of passive solar design. It includes technologies and engineering features, which require a very small amount of energy (or no energy) to operate, and yet significantly enhance the performance of the prerequisite passive solar design strategies. These technologies and engineering features include: life cycle and integrated design processes; various building envelope thermal insulation products; high performance building façade systems (e.g., insulated composite panels, double/ triple glazing systems, etc.); and daylight harnessing technologies (e.g., light shelves, skylights and light pipes). The characteristics of these technologies are:

a) They require additional but feasible efforts during the building design and construction stages

b) Once installed, they require little to no additional effort to operate and maintain (e.g., cellular plastic insulation products, cool paints, self-cleaning façade solution, etc.)

c) They have very short or reasonable returns on investment, except for the high-end building façade systems (e.g., double skin façade system, triple glazing operable system, photochromic glazing, and electrified glazing).

These technologies and engineering features are often found in newly constructed buildings. Building envelope thermal insulation is also popular in the renovation of existing buildings. This is especially so in temperate countries, where it is used to improve the thermal performance of buildings during cold seasons.

Life cycle and integrated design processes are also highlighted under this typology as good design practices to engage multidisciplinary team members to address all aspects of building design, including life cycle considerations, at the early stage of building brief formation and design. These processes provide a platform to deliver high-performing buildings in a cost effective manner. Furthermore, the availability and ongoing development of computer simulation technologies allows building's environmental performances to be predicted, such as daylighting, sunlight exposure and natural ventilation. Therefore, computational simulation technologies can help facilitate the integrated design process, such as assisting decision making for highly energy efficient buildings.

3. Active design

Active design typology encompasses technologies, equipment and appliances that are highly energy efficient in terms of delivering the same building performances and services, compared to their counterpart products. The focused technologies include efficient lighting systems, efficient heating, ventilation and air conditioning (HVAC) systems, and water efficient technologies. Technologies related to water efficiency have an indirect but large impact on climate change, due to the large amounts of energy required to purify and distribute potable water for use in buildings. For these reasons, water efficient technologies are included as a mitigation option.

The application of the technologies in the active design typology, in general, requires additional financial resources to invest, operate and maintain. Many of these technologies also require highly-skilled professionals and technicians to design, install and operate them. While the studied technologies are best deployed during the building design stage for optimal energy efficient performance, most of them can be used when upgrading the performance of existing buildings.

4. Low carbon and carbon sequestration

While the above three typologies focus on energy efficiency performance of buildings, the low carbon and carbon sequestration typology allows buildings to have low embodied carbon and even to offset some of the carbon they emit. These are achieved by:

a) The use of low-carbon building materials, the main criteria for which include being locally-available, being recyclable, and containing recycled materials

b) The use of carbon-trapped materials, such bamboo and wood products from sustainably managed sources. These materials endow buildings with some carbon storage capacity thanks to the large percentage of carbon captured in the plants

c) The use of building integrated greenery systems, such as green roofs, roof gardens, balcony gardens, sky terraces, and green walls. These integrated greenery systems allow buildings to sequester carbon, while cleansing ambient air, lowering the urban heat island effect, and providing pleasant visual relief for building users.

These materials and technologies are often deployed at the design and material selection stages for new buildings. The installation of low-carbon and carbon-sequestration building materials can also be carried out during there renovation of existing buildings. The specification of low-carbon and carbon-sequestration building materials do not usually involve additional cost or maintenance. However, building integrated greenery systems require ongoing investment and maintenance.

5. Onsite renewable energy generation

This mitigation typology offers buildings the opportunity to generate energy from renewable sources for onsite consumption and for exporting to the electricity grid. Onsite renewable energy generation also contributes to and facilitate the effort to switch energy from fuel-based to renewable sources. Technologies highlighted under this mitigation option for buildings are solar technologies and building integrated wind turbines.

While many solar technologies (e.g., solar thermal water heaters, building integrated photovoltaic systems, solar home systems, and solar charging stations) are proven technologies and have even been deployed widely in many countries, building integrated wind turbines are still at the market penetration stage. While building integrated renewable technologies are best implemented for new buildings as the system's performances are optimised at the outset, solar thermal water heaters, solar home systems and solar charging stations can be implemented in both new and existing buildings. Onsite renewable energy generation is, in general, a costly mitigation option, and often implemented in developing countries using international support and/or government subsidies.

6. Monitoring and occupants' feedback loop

This mitigation typology includes technologies and practices that verify, monitor and manage energy performance at the commissioning and operational stage. Practices and technologies include verification of energy performance at commission, building energy management systems and energy performance contracting. The objectives are to assess, maintain and improve targeted energy performance, and allow positive occupancy feedback loops.

Technologies acting as catalysts for behaviour change (such as energy efficient appliances, home area networks and pre-paid meters) play an important role in this mitigation typology. It is because positive occupant behaviours towards a sustainable lifestyle and being less wasteful of electricity are key solutions to climate change mitigation. The highlighted technologies include making data related to energy consumption in the building visible to the occupants, and making the benefits of being energy efficient tangible to the occupants.

Most technologies and practices under this mitigation typology are highly applicable to existing buildings, except for verification of energy performance at commissioning (which is also applicable to new buildings). The cost implication of this mitigation typology to building's owners/developers ranges widely, from non-additional financial requirement for energy performance contracting, to the costly installation of sophisticated building energy management systems and home area networks. It is worth mentioning the positive contribution of energy performance contracting that acts as green financing mechanism targeting large existing building stock for the replacement of old and inefficient mechanical systems to energy efficient ones. The practice also has the potential to unlock the financial bottleneck for large-scale implementation of renewable energy technologies in developing and least developed countries.

7. Beyond individual buildings

It has increasingly been recognised that climate change mitigation can be effectively addressed at the community scale, which in turn supports the implementation of the mitigation typologies at the building scale. This mitigation typology, as such, addresses a larger number of targeted people, and includes:

a) Sustainable community design and practices, which consist of planning, designing, building, managing and initiating social and economic development of communities, gearing toward sustainable development objectives

b) Community based energy services, which are often found in the form of district heating/cooling and renewable energy generation (e.g., combined heat and power generation).

Both groups of technologies and practices can be initiated and implemented to new and existing communities. It is noted that planning and designing techniques for sustainable communities are also applicable to the improvement of the physical condition of an existing community. The implementation of community based energy services can be capital intensive, whereas sustainable community design and practices can be implemented with more flexibility in terms of financial requirements. In fact, the low income community model requires little upfront financial investment (usually from NGOs or governmental supports) but generates stable long-term social and economic gain for the community (e.g., through the creation of green jobs). In this model, some of the financial gains are used to improve the physical built environment for the community.

4. Mitigation Technologies and Practices in the Building Sector

4.1 Innovative use of traditional building materials and design

The technology

The use of traditional building materials and design is often found itself in a difficult situation, that is either being under the threat of perished under the force of modernisation or being innovatively implemented to meet modern building standards and living conditions. Traditional building materials and design have gained renewed attention in the green building movement, thanks to the use of locally accessible resources that address local conditions in a cost effective way.

Many traditional building materials have benefited from innovative technologies in both manufacture and application. These developments have made several traditional building materials more financially feasible, environmental friendly and technically sound. The following examples highlight practices and technologies that contribute toward mitigating climate change.

Earth-related building materials. In many non-urbanised areas in India, East Africa and South America, raw earth is abundant resource, which has popularly been used as building material. Over times, modern technologies have renovated the use of raw earth materials to improve their performance. For example, raw earth materials are converted into compressed earth blocks, made of a semi-dry mix of clay and sand and produced using a mechanised hydraulically compressed block machine. These blocks are reported to have a load-bearing strength two-thirds that of concrete masonry blocks (Mehta et al., 2004). A further improvement is achieved by mixing earth with a small percentage of cement during the production process to create compressed stabilised earth blocks. These blocks have better compressive strength and water resistance, and allow for thinner, higher walls to be built. Stabilised compressed blocks also take 3-5 times less energy to produce compared to conventional fired bricks (Auroville Earth Institute, 2009).

Stabilised rammed earth foundation is an innovative application of earth-related building materials. The soil, which is excavated from the trench foundation, is sieved and mixed with cement and sand to become construction materials for the building foundation. Stabilised rammed earth foundation has been reported to be used for buildings up to four storeys in height (Auroville Earth Institute, 2009).

Figure 4.1.1: Stabilised rammed earth foundations under construction process in India

(Source: Auroville Earth Institute)

Traditional Chinese practices of building orientation and interior space organisation was based on the belief of enhancing occupants' health and wealth by tapping into the characteristics of natural materials and directional coordinates e.g., placement and orientation of windows, doorways, passages, interior and exterior layouts according to certain principles to promote positive 'air and energy flow' within a space. Such arrangements are believed to promote the positive health (mind and body) of occupants. The belief used to be criticised as having no scientific proof. However, recent research shows that many principles in these traditional practices of building orientation and interior space organisation are in line with certain sustainable building principles (Zhong et al., 2007). Furthermore, modern interpretations of certain traditional practices show that they are in line with the principles of sustainable building design. Some examples are highlighted in the next session – Application requirements.

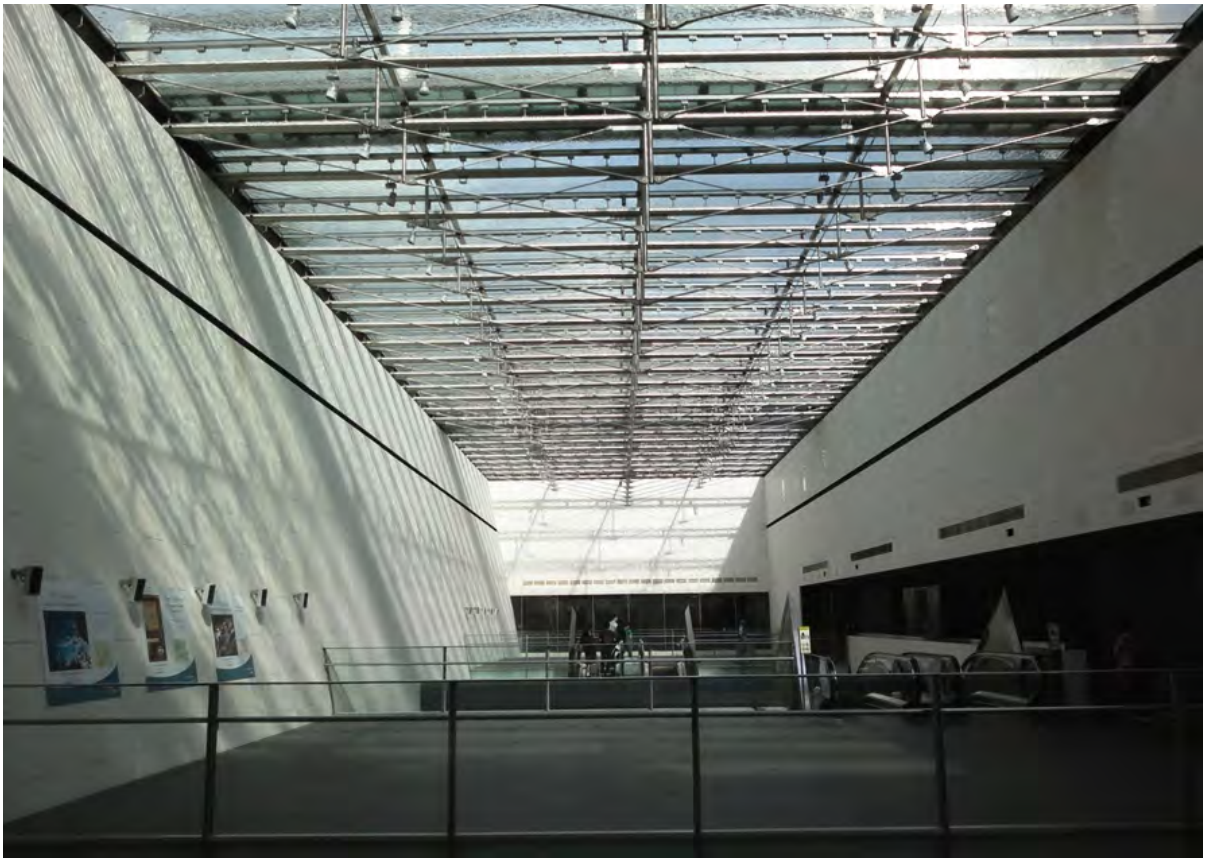
Traditional building design strategies in the Mediterranean demonstrate that local wisdom involves designing with the local climatic conditions in mind. Traditional Mediterranean buildings are generally oriented to the south with a long east-west axis, to respond to solar direction and summer breeze. A courtyard and a solarium (an internal space adjoining the courtyard) act as climate moderator for the whole building, and are almost always found in Mediterranean traditional building. Some key functions of the courtyard include creating a microclimate, e.g., providing shade and evaporative cooling during summer, and allowing sunshine during winter through planting deciduous vegetation, high external wall, water features, etc.

Traditional Mediterranean buildings have thick walls which are built from stone and sun-dried mud-brick and rendered with mud plaster. These materials allow the thick wall to smooth out the large diurnal temperature variations in summer, and to act as thermal mass to warm up the internal space at night during winter. The walls are also painted in white (which can still be seen on buildings on Greek islands) to reflect the harsh solar radiation of the arid climate. Small windows are strategically located high on walls to foster cross ventilation during the summer, and are closed with small dense bushes (acting as thermal insulation) during winter. Deep recessed windows on walls and overhang from elements such as balconies act as sun shading devices (Lapithis, 2004).

Water-cooling envelope works based on evaporative cooling principle, in which the air temperature drops when the air volume takes up water by transforming it from liquid to vapour. The principle is applied through providing water film over the surface of building envelope, especially the roof, to bring down its temperature below the ambient air's temperature. The roof surface will then act as a means for heat to be transmitted from inside the building to the ambient air. The process cools the air without increasing the humidity inside the room, and thus improves the room's thermal comfort level.

Innovative implementations of this principle include the installation of water sprayers on the roof, or roof-pond systems. The roof-pond system includes a water pond on the roof with operable reflective insulation. During hot summer days, the reflective insulation covers the whole pond and protects it from solar heat gain. The water body keeps receiving heat from the space below through the roof, and as such, cools the space below. During the summer night, the insulation is removed and the heat stored in the water body is released to the outdoor ambient air through evaporation, convection and radiation. During winter days, the insulation is removed so that the water and black surface of the roof absorbs solar radiation, and warms up the space below. During winter nights, the insulation covers the whole pond, so that the water body becomes thermal mass to keep the space below warm.

Figure 4.1.2: Modern application of water-roof system to bring benefits to both thermal comfort and daylight to building interior



Another form of water-cooling envelope is found in some heritage Indian buildings, in which water pipes are installed inside the walls to cool the building. The application of water-cooling walls in the Lotus Mahalis an example. When the ambient temperature is higher, water in a storage tank is circulated in the hollow place inside the wall, and cools the building (Panasia Engineers Pte. Ltd., 2010).

Wind towers: also known as wind catchers, apply evaporative cooling principles inside a building to supply cool air to ventilate the internal space. Wind towers are traditionally used in the Middle East, where daytime air temperature is high and humidity is low. A typical traditional wind tower comprises an air inlet facing the prevailing wind direction to scoop the wind into a vertical shaft. Immediately behind and below the air inlet is an earthenware jar of water, which is taken up and transformed into vapour by the dry air wind. During this evaporative process, the air becomes cooler and sinks. This reinforces the air movement downward, providing a draft of cool air to the interior. After the whole day exchanging heat, the wind tower gets warm in the evening. Therefore, a reverse airflow pattern occurs during the night, when cooler room ambient air comes in contact with the bottom of the warm shaft, becomes warm and rises. Such air movement, while providing ventilation to the interior space, cools the surface of the tower to be ready for the next daytime operation. Renovations to the application of the traditional wind towers include the design of moveable air inlet, which can automatically track the wind direction for more constant cool air supply to the room (s), and the use of mechanical mist spray instead of water jars to reduce maintenance needs.

Application requirements

As most of the traditional building materials and technologies originate from rural settings, they are suitable for low-rise and low density settings. Renovation and the innovative use of such materials and design techniques keep them relevant to the modern building standards, to meet occupants' aspiration for better lifestyles, and to overcome the engineering pitfalls, so that they can be applied in larger scale buildings to meet the global trend of urbanisation. To be main streamed, the renovation and innovative use of traditional building materials and design must meet more stringent building standards, especially requirements related to safety and environmental health.

Earth-related building materials. Soil types from different local contexts have different characteristics, which result in different load bearing strength, and require different ratio of mixture with cement and sand to reach certain strength performance. Prior to application in a building structure, it is crucial to research and test the performance of such materials to safeguard construction safety issues.

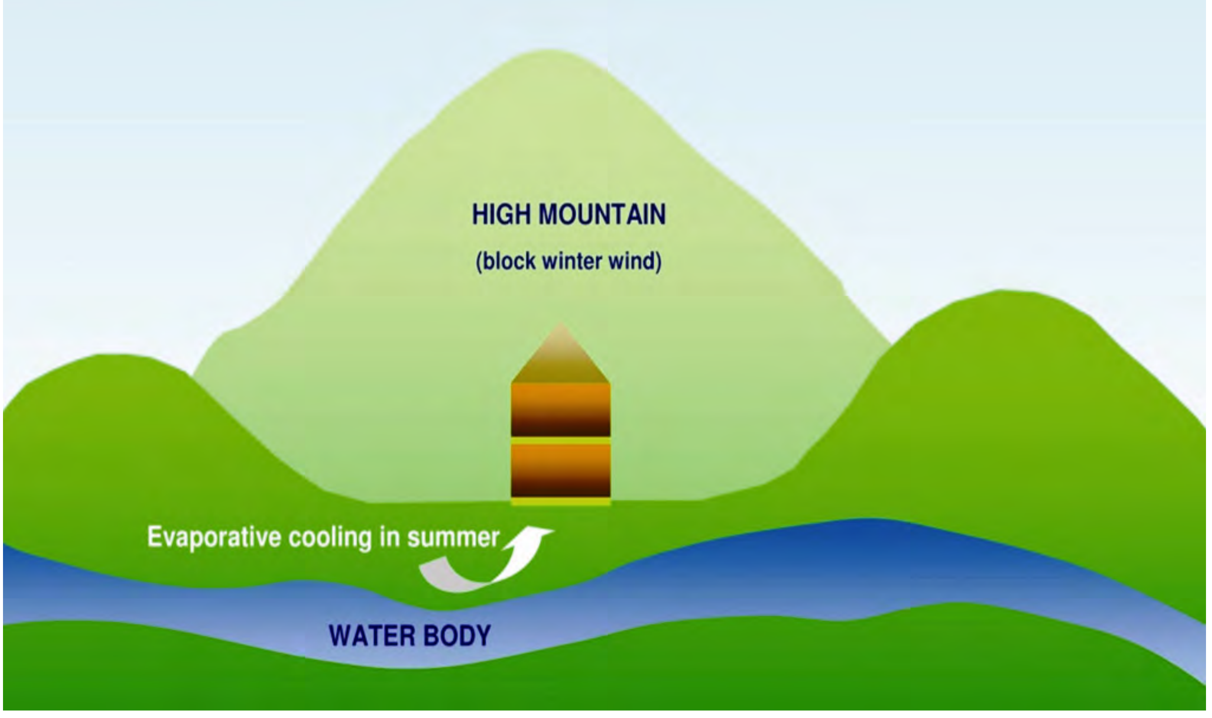
On the other hand, an important application requirement for a stabilised rammed earth foundation is that the width of the foundation is recommended to not be smaller than its depth. This is because earth has high compressed load bearing but is weak in terms of withstanding shearing forces. The force of the building's walls, more so in columns, will create pointed loads on the foundation. These pointed loads create shearing loads at the bottom of the foundation. Therefore, a foundation section with a depth smaller than its width is weaker and can easily fail to sustain such shearing forces compared to a deeper foundation. A way to mitigate such loading issues is to reinforce the foundation with a sub-frame, such as metal, wood and bamboo.

Traditional building design strategies in the Mediterranean demonstrate a range of passive solar design strategies and techniques to bring environmental comfort to occupants. In a traditional Cyprus house, for example, the solarium and courtyard function as climate modifiers (Serghides, 2010). The solarium is an internal space, adjoining the courtyard. Its south elevation opens to facilitate the seasonal indoor-outdoor flows of daily activities (e.g., cooking, washing, eating and so on). The south-facing overhang of the solarium is designed to allow winter sunlight to penetrate deep into the space. The south-facing courtyard acts as a sun space. Both the solarium and courtyard are made of high thermal mass materials, such as stone paving, adobe walls, stone staircase and pools, to create a more pleasant microclimate along the long front facade of the house. The front wall of the courtyard also acts as buffer to cold winds. During summer, planting and soft-scape in the courtyard provide shade and a cool microclimate in front of the house. The pool and fountain in the courtyard provide evaporative cooling. The designs of arches, overhangs and openings on the wall facing the courtyard help channel summer breezes into the house. Openings are small on the east- and west- facing walls to avoid hot summer sun. Thermal mass materials in the courtyard and solarium absorb the heat during the day and release back to the ambient air at night effectively due to the large diurnal fluctuations of temperature in the hot arid Mediterranean region.

Traditional Chinese practices of building orientation and internal spatial arrangement require a good understanding of the logic behind each principle in order to maximise the environmental performance benefits scientifically. For example, one of the traditional practices describes that it is ideal for a house to have its front orientated toward a water body to the south, and the rear of the house backed by a hill slope on the north. Mapping this approach to the climatic conditions in many regions in China shows that:

1. The prevailing winter wind direction in general comes from the north. Therefore, the hill slope on the north protects the house from cold winter wind
2. Due to the northern latitude location, sunlight accessibility comes from the south. Therefore, by orientating the front of the house with windows facing south, low-angle winter sunlight can penetrate deep into the interior, providing natural warming effect, and enhancing thermal comfort for the occupants
3. The prevailing summer wind direction generally comes from the south. Together with a water body, the wind creates a more comfortable microclimate, enhanced by evaporative cooling in front of and surrounding the house.

Figure 4.1.3: Traditional Chinese practice of building orientation



Water-cooling envelope is ideal for hot and arid regions, such as north-western India, However, it is less effective when applied in the hot and humid regions within the tropical belt. The reason is that the high humidity in the air reduces the effect of evaporation, and that the variation of outdoor air temperatures between the day and the night is minimal. As the water-cooling envelope in the roof surface is constantly in direct contact with water, a good roof water-proofing system is required. In the case of roof-pond system, it is important for users to understand the system's operational logic, so that the system can function as intended.

Wind towers do not function in hot and humid regions, due to the high humidity of the outdoor ambient air. They are highly applicable in hot and arid climatic regions such as the Middle East, Sub-Saharan Africa, and north-western India. The dry air and the wide range of day and night temperature are key to the function of wind towers. Wind towers require frequent maintenance to keep the water jar clean, to refill water, and prevent birds nesting in the tower.

Implementation status and market penetration

The implementation status of renovation and the innovative use of traditional building materials and design, varies depending on the individual techniques and practices in a particular local context. Some are thriving and others are under threat of being lost. As most of the traditional building materials and design originate from rural settlements and are suitable for low-rise and low density settings, they are becoming obsolete under the pressure of urbanisation, particularly in developing countries. Although their renovation and innovative use can help modernise their quality and application, the results have certain limits. Below are some observations regarding the implementation status and market penetration of renovation and the innovative use of traditional building materials and designs:

1. If a rural area is earmarked to be urbanised to become a small town (e.g., those with building height of about 3-4 storeys), earth-related building materials can thrive if their quality, performance and aesthetic quality stay close to those of masonry products. The lower cost and availability of local resources help them stay competitive. Water-cooling envelope, Mediterranean design principles, wind towers and the traditional Chinese practice of building orientation and interior space organisation may stay relevant.
2. If a local area is earmarked to be urbanised to a medium to high density town/city, it is difficult to implement earth-related materials. Furthermore, raw materials such as soil and vegetation may be less abundant or no longer available locally. The traditional Chinese practice of building orientation and interior space organisation (thanks to its indoor application component), is largely unaffected by higher density urbanisation and is still applicable in such context. Likewise, the traditional Mediterranean design principles, i.e., thicker walls (especially on the east and west facing walls), solarium and courtyard, overhang, balcony, etc. – also remain relevant in a higher density urban context.
3. From a lateral inter-regional relationship perspective, there is a huge potential for South-South transfer, especially between regions with similar climatic conditions, for most renovation and innovative use of traditional building materials and design. This is largely due to similarity in local materials i.e., soil, sand, wood and bamboo – available in most regions. What needs to be transferred are the principles, technical skills and equipment.

Feasibility for implementation

The implementation of traditional building materials and design has already taken place at a local level at many regions in the world. However, the pressure of urbanisation and the aspiration of living in modern houses with modern materials, finishes and technologies have led to the gradually phasing out of such materials and design. Innovative use of such materials and design help keep them upgraded to meet the new demands and expectations. In such context, the main challenge for large-scale implementation is to overcome the negative perception of such innovative use of traditional building materials. For example, earth-related materials are often perceived as building materials for the poor.

Figure 4.1.4: Pressure of urbanisation found in many Asian nations

Capacity building and re-education is required for local architects, engineers and constructors in order to broaden the adoption of these practices. To do so, good pilot projects to demonstrate the quality and performance of such materials and design are useful. Such demonstration projects can be initiated by local governments or NGOs in collaboration with the private sector and supported by local government. The second model has been reported to be popular and effective in Africa, where NGOs take on the liaison role between government agencies and the local communities. NGO involvement helps reduce bureaucracy and free the government agencies from the day-to-day running of the project (Mehta et al., 2004). Capacity building and training workshops are useful and can be held by NGOs to upskill local work forces on new techniques and innovative applications of traditional building materials and design. The operations of NGOs will be more fruitful with supportive government policies.

Contributions to social, economic and environmental development

Innovative use of traditional building materials and design are relevant and beneficial to developing countries, especially least developed countries, because of the following characteristics:

1. Well-established and proven technologies and practices, which are updated for better performance and innovatively used for wider application in the local context, where they are implemented
2. Appropriate to local climatic conditions, and as such being energy efficient with little effort
3. Using locally available and accessible resources, to reduce the need for transporting materials from afar

4. Nurturing local building material manufacturers
5. Alleviating shortages of construction materials for certain regions and nations during construction boom periods
6. Providing job opportunities for local work forces, whose skills and experience are readily relevant, due to the familiarity to the materials and techniques involved.
7. Low-cost to no-additional cost for implementation
8. Resulting buildings that are socially and culturally familiar to the users.

Financial requirements

Appropriate renovation and innovative use of traditional building materials and design usually require no additional to very little additional financial investment, due to the readiness of local work forces and availability of local resources. For example, compressed earth blocks or stabilised rammed earth foundations are the main material sources for many low-cost but good quality houses in rural India and Africa. The implementation of wind towers and water-cooling envelopes require financial arrangements for additional construction costs and maintenance. The traditional Chinese practices of building orientation and internal spatial arrangement are cost-free to implement, as these practices and techniques do not require additional technologies or materials to be implemented.

Case study

Movable house, Auroville, India:

The house is a pilot project to build a simple but movable house to address the housing shortage in Auroville, an area with no formal urban design master plan. The concept is to provide affordable houses with renovation and the innovative use of traditional building materials in a short time frame on a permitted temporary location. However, the house can be dismantled, transported and rebuilt at a permanent location with a minimum waste of materials, once the master plan of Auroville is firmed up.

Technically, the entire house was precast, including stabilised compressed earth blocks for walls and columns. In order to be dismantled with minimum materials lost, no cement mortar or cement concrete were used. The blocks were specially designed to allow interlocking joints. Earth mortars were used in place of cement, and wooden building materials were used in place of steel, in order to assemble a structure that is earthquake resistant. The simple wall construction techniques can be laid by semi-skilled labour. The construction of the house took only 64 hours on site by a team of 16 paid workers and 10-15 volunteers. The 30m^2 house, including a solar system, water supply, wastewater system and all finishes, was completed in 2008 and cost only about US$5,000 (Auroville Earth Institute, 2010).

Figure 4.1.5: Movable house in Auroville, India under construction (left) and completion (right)

Source: Auroville Earth Institute

4.2 Passive house design and technologies

The technology

Increasing awareness of energy efficiency and climate change has led to new developments in the building sector, including the concept of passive house, low carbon buildings, and even zero emission buildings. Low carbon houses and zero emission buildings achieve their common objectives by applying all available green design techniques, strategies and technologies. Due to this broad definition, a building can be considered as low carbon or zero emission by installing onsite renewable energy technologies (see section 4.12 and 4.13), or simply by tapping into off-site zero emission energy sources, such as hydro, wind farms, etc. (Torcellini, 2006). On the other hand, the concept of passive house focuses on the energy efficiency aspect of the building. Passive house takes the conventional passive solar building design principles as a starting point and combines them with an air-tight and well insulated building envelope to derive very low energy buildings. The heating requirement for passive house buildings is targeted to be as low as 15kWh/m^2/year in Germany, compared to 250kWh/m^2/year to heat an average apartment there. The Passive House Institute defines a passive house as “a building in which a comfortable interior climate can be maintained without active heating and cooling systems” (Passive House Institute, 2010).

A typical passive house is a well-insulated and highly air-tight building, with stringent design and construction standards. It is primarily heated by passive solar and other internal heat gains, and equipped with an energy recovery ventilator for a constant and balanced fresh air supply.

Application requirements

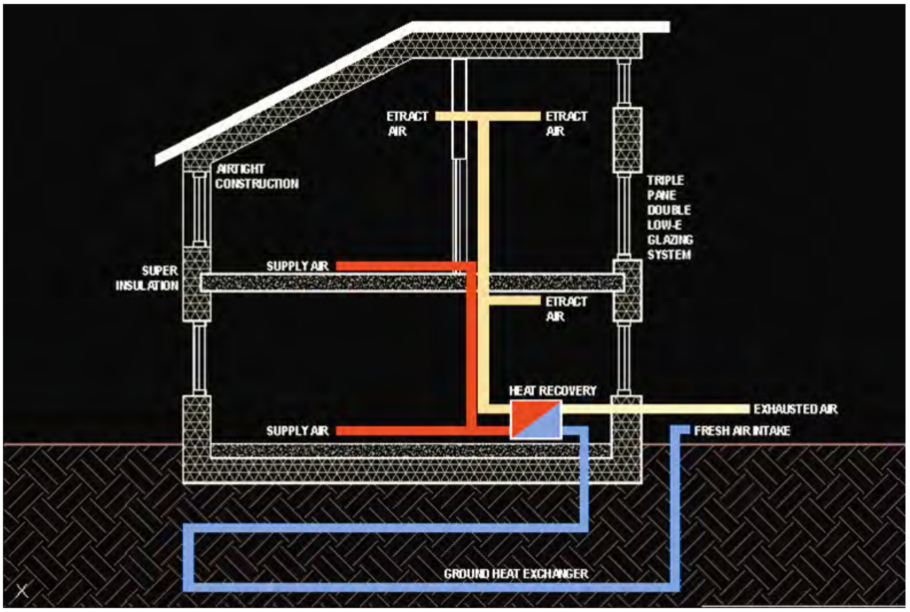
As a starting point, passive house design addresses and exploits elements from the building’s surrounding context (e.g., land form, sun, wind, rain, vegetation, etc.) and organises the interior of the building to maximise energy savings and indoor environment quality. In addition, passive house design and technologies have to address the following:

1. Excellent insulation: the insulation standards are very stringent in order to limit thermal loss through conductivity and radiation.

2. Air-tight construction: in order to complement and not deplete the insulation performance, air-tight construction is required to limit thermal losses through direct air flow between indoors and outdoors.

3. Ventilation with heat recovery: with air-tight construction, operable windows are not favoured as they have great potential for thermal loss. Fresh air intake for ventilation is instead taken from energy-and-heat recovery ventilators, which transfer the thermal energy from discharged air to incoming fresh air to make the temperature of incoming air close to that of the indoor air temperature. An additional opportunity exists to channel incoming air through ducts buried underground. The constant earth temperature, which is often warmer in the winter and cooler in the summer, helps pre-heat/pre-cool the incoming air. The process is also known as subsoil heat exchange. Afterward, the pre-heat/pre-cool air will go through the above mentioned heat-recovery process (Feist, 2005).

Figure 4.2.1: Super insulation, air-tight construction, and ventilation with heat recovery system



Passive house design and technologies are most appropriate for temperate climate conditions, such as Europe and North America. Although the concept of passive house has been expanded to other climatic regions, the principles of air-tight construction and super-insulation are still being debated, especially their application in warmer climatic conditions. The following application requirements are discussed within the proven application parameter in temperate climatic context, which is where passive house design technologies were originally developed.

In order to achieve its objectives, a passive house has to first deploy all design strategies to meet climate responsive design principles. The key principles are:

1. Good orientation: to respond positively to land form, sun path and seasonal prevailing wind directions.

2. Self shading design: where windows or glazing areas are exposed to hot afternoon sun, they should be shaded by other components of the buildings, such as balconies above, planter boxes, roof overhang, or sun-shading devices.

3. Compact form: to reduce building envelope area and thus heat loss.
4. Spatial organisation: to locate less habitable areas, e.g., storeroom and bathroom, on the western side of the building to act as additional thermal buffer; and to expose living room with glazing/ window toward the south for sunlight accessibility.

In addition to the above, some application requirements to achieve the key passive house standards are:

1. Insulation: besides providing sufficient insulation (see Section 4.4) in the building envelope, it is important to pay attention to prevent thermal bridges through weak areas by using a triple glazing system for windows, careful construction details at joints between floor slab and walls, walls and window frame, the window frame itself, wall to ceiling, and roof construction.
2. Air-tight construction: operable windows and doors should be detailed with air-tight construction, especially along the edges of door and window panels. As a guide, these unsealed joints should have air leakage of less than 0.6 times the house volume per hour.
3. Air quality control measures: with air-tight construction, indoor air quality becomes more important to occupants' health. Therefore, air quality control measures should be undertaken during design and construction stages. These include, but not are not limited to: selecting building materials and adhesives with low/no volatile organic compounds, and carrying out a proper flush-out procedure, in which the newly completed buildings are fully opened for air circulation for a required continuous period before occupancy.
4. Ventilation system: heat recovery from exhaust air using air-to-air heat exchanger is applied to achieve a recommended 80% efficiency. It is also important to locate the warm air ducts inside the heat envelope and cold air ducts outside (Passive House Institute, 2010). However, in warm climatic regions, the opposite is recommended.

To achieve the above key stringent standards, many building science research projects related to passive houses have been carried out, leading to the development of software called Passive House Planning Package (PHPP). PHPP is an energy modelling programme that projects energy usage in the building design by taking into account almost every aspect related to energy consumption, including the site's weather data, orientation, type of construction, materials used, window designs and locations, ventilation system, appliances, lighting and other electrical equipment used in the building. As more post-occupancy data has become available and the concept of passive houses has been expanded to other regions of the world, PHPP has been continuously upgraded and refined, including the addition of simulations for other climates around the world.

Implementation status and market penetration

The main market of passive houses is in Europe, with Germany and Austria taking the lead, with a smaller market in North America. As of May 2009, it is estimated that there are about 19,100 passive house projects in Europe (Lang, 2009). Passive house projects are anticipated to be widely adopted in the construction and property market in Europe. It is projected that by 2015, there will be about 260,000 passive house projects in Europe with a total floor area of about 85.2 million square metres of new buildings and 6.2 million square metres of retrofitted buildings (Lang, 2009). Among developing country regions, Eastern Europe has the highest market penetration prospects for passive house design and technologies, thanks to the similar climate and the geographical proximity to other European regions, where the passive house concept has been taken up and implemented.

Passive house design and technologies are not limited to residential buildings. In recent years, other building types, such as schools and offices have also applied passive house design and technologies, which deliver good energy efficiency results.

Feasibility for implementation

Different regions have different: climatic conditions, availability of construction materials and conventional practices. Even within the temperate regions, the difference in extreme temperature, humidity, opportunity for geothermal, etc., can still be identified. Therefore, while the principles of passive houses and related technologies can be applied in various temperate regions, the actual quantitative standards and construction detailing can vary. It is useful for a local area to have an overall feasibility study and to undertake research on the most suitable practices and standards for passive houses. The findings can then be used to form design guidelines and standards, which serve as a reliable springboard for large-scale adoption.

Although passive house principles and technologies can be taken up by individual building owners and potential building owners through a bottom-up approach, good support from institutional settings, such as local building codes based on passive house principles and supporting demonstrations in public building projects, can facilitate stronger uptake and implementation.

Passive house technologies require highly skilled technicians to implement good and precise construction details i.e., air-tightness, no thermal bridges, etc. Therefore, capacity building and local workforce training are key requirements.

It is also noted that many developing countries do not have the manufacturing capacity to locally produce passive house components and materials, e.g., insulation, triple glazed windows, etc. Importing these components and materials are too expensive and increase the embodied carbon of the products. Therefore, it is important to extend capacity building and institutional settings to support and nurture local manufacture's uptake and upgrade for the production of passive house components and materials.

Contributions to social, economic and environmental development

Passive house design and technologies bring benefits to environmental development, including energy saving for artificial lighting, heating, ventilation and air conditioning. Due to design optimisation for daylight and thermal comfort, passive house design and technologies offer building occupants better thermal comfort, indoor environment, indoor air quality and visual connection to outdoors. These benefits lead to a healthier and higher quality of life.

Due to the fact that passive house design and technologies do not rely on active systems and high-tech equipment to deliver environmental benefits, passive house design and techniques can also be considered one of the cost effective mitigation options. The resulting lower energy demand from passive houses helps reduce electricity peak load, and create further savings by avoiding additional investment to increase the capacity of the local power infrastructure and power plants.

The promotion of passive house implementation also helps upgrade the skills of local construction work forces and improve building and living standards for the local residents. This results in better job prospects, healthier communities and greener economies.

Financial requirements

The implementation of passive house principles and technologies incurs some additional investment cost to provide high-performance envelope insulation, triple glazing windows, air-tight construction, heat-recovery ventilators, stringent construction details and so on. However, it is argued that an incremental investment cost can be balanced by avoiding costs of investing in sophisticated heating, ventilation and air conditioning (HVAC) systems and their high operating costs. Instead of investing in HVAC systems, passive houses invest in better building envelopes, which also improves the building's durability and its life span. As a rule of thumb, a passive house is considered to be cost effective when "the combined capitalised costs (construction, including design and installed equipment, plus operating costs for 30 years) do not exceed those of an average new home" (Passive House Institute, 2010).

Case study

Bragadiru Office Building, Ilfov, Romania:

The project is a new administration building, masonry construction with a floor area of 2,400m^2. This project is the first office building in Romania to apply passive house technologies. The building envelope is partially insulated through the use of insulating concrete forms (ICFs) made of Neopor fabric. ICFs are easily assembled by filling them with concrete on the construction site. The finished interior and exterior walls are monolithically moulded concrete walls with good insulating properties. The walls are further thermally insulated by polystyrene with a density of 24 kg/m^3 on the exterior, and cellulose fibre on the interior. Polystyrene and cellulose fibre are also used to insulate the roof. The building ventilation system uses heat recovery to pre-heat and pre-cool the fresh air intake in winter and summer respectively.

The resulting building has a low heating energy requirement. It was verified by the Passive House Institute in Darmstadt through the PHPP verification method. The result shows that annual heating energy demand is 15kWh/m^2 (Passivhaus Datenbank, 2010).

Prefabricated buildings with passive house principles, China:

The concept, techniques and technologies of passive house have innovatively been adopted by Broad Sustainable Building in their prefabricated building prototypes. These building prototypes are prefabricated with highly insulated components, including up to 400mm of exterior wall insulation, and triple-glazed windows with external solar shading.

Since walls and windows are completely insulated, the indoor air temperature can be kept constant. Although the ventilation system supplies more than one complete air exchange per hour with no mixture of indoor and outdoor air, a heat recovery device helps to maintain the desirable temperature with minimum energy required. In a cold climate region, the heating energy required for these buildings can be as low as 20kWh/m^2. As the building components are prefabricated, workmanship quality (especially air-tight construction) can be better coordinated and controlled; also construction waste and other environmental impacts (such as noise and dust) during construction are minimised. The construction time on site can be reduced significantly, i.e., a four to six-storey building can be erected on site within a day. Building prototypes that have been implemented include residential apartments, offices, an exhibition centre and a hotel (Broad Sustainable Building, 2010).

4.3. Life cycle and integrated design process

The technology

The life cycle and integrated design process can be understood as a design process to deliver a building, in which its relationship to the surrounding context, technical components and technologies are parts of a whole system, for the whole building life cycle (Larsson, 2005). This objective can be obtained once interdisciplinary professional team members work collaboratively right from the inception and conceptual design to make strategic decisions and address all design issues. In this way, energy efficient technologies and strategies can be incorporated into the building design in a way that is integral to life cycle considerations.

Such results are often not achievable using a conventional linear design process, which usually begins with the architect and the client agreeing on a design scheme. The mechanical and electrical engineer and the civil and structural engineer are then asked to provide their inputs according to the agreed design scheme. The engineers, therefore, are tightly bound by the earlier agreed upon design parameters. As a result, their inputs for energy efficiency are usually not optimal, but rather add-on features or an attempt to rectify inefficient design decisions made earlier. For example, for a pre-agreed built form that exposes large building glazing to the west, engineering inputs are limited to the selection of an energy efficient glazing system and to provide additional air-conditioning load by choosing an energy efficient HVAC system. This result is far from optimal and it unnecessarily increases the overall building cost. Furthermore, from the life cycle perspective, the high embodied energy of the additional HVAC equipment and large area of double or triple glazing panels used to reduce heat gain on west façade can be considered as wastage. A better approach is to have these issues raised and solved at the conceptual design stage through the life cycle and integrated design process; and perhaps the issues caused by large glazing façade on the west façade can be avoided altogether.

The typical elements of life cycle and integrated design process can be clustered into three groups:

1. Interdisciplinary and interactive approach: an interdisciplinary team should be formed right from the project's inception. The involved parties, depending on the complexity of the project, are the client, architect, engineers, quantity surveyor, energy consultant, landscape architect, facility manager, contractor (builder) and design facilitator (in more complex projects) (Lohnert et al., 2003). The team members first establish a set of agreed performance objectives, and work collaboratively to achieve these objectives.

2. Lifecycle based decision making: Decisions made during the design process, such as built form, orientation, design features, building materials, structural systems, mechanical and electrical equipments, should be based on a lifecycle assessment. The assessment should take into account the products' or systems' embodied energy, performance, lifecycle cost, lifespan and end-of-life.

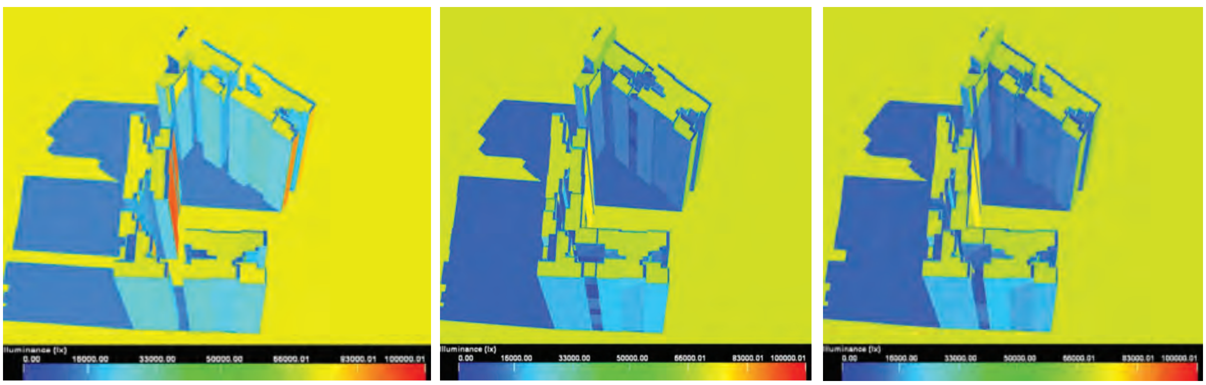
3. Computer assisted design tools: the design of sustainable buildings has recently been made easier with growing number of computer assisted design tools. These tools simulate building environmental performances, and calculate the energy required for cooling or heating, CO_2 emissions, life cycle

analyses and so on. Simulation tools predict building environmental performance, usually for aspects such as sun path and sun shadow, daylight, computational fluid dynamics for air movement, etc. The tools make design strategies visible through graphic-based user interfaces. They are particularly useful for:

a) Providing feedback to inform the design process. For example, a sun path analysis provides outputs that allows the design team firstly to identify the areas requiring sun shading devices, secondly to design the form and dimensions of sun shading devices for them to be effective, and thirdly to simulate and verify the performance of sun shading devices on the building model.

b) Comparing different design options, strategies, and technologies to facilitate the interdisciplinary team's decision making process.

Figure 4.3.1: Daylight simulation of various design options to facilitate decision making process



Computational simulation technologies have also been rapidly developed to facilitate decision making during the design process to enhance the environmental performance and cost effectiveness of buildings. The five main areas for which computational simulations are usually applied are listed below, with examples of software:

1. Sun path and sun shadow simulation: ECOTECT
2. Daylight and glare simulation: Radiance, Daylight, DAYSIM
3. Thermal simulation: TAS, IES
4. Computational fluid dynamics (CFD): CONTAM, FLOVENT, FLUENT, IES
5. Energy demand and supply balance: Energy Plus, eQuest.

In recent years, individual computer assisted design tools have gradually been replaced by an integrated, one-stop computational platform, that can serve as a drafting tool, visualisation tool, simulation of various environmental performance, local code compliance checking tool, and even a facility management tool. An example is Bentley Tas Simulator software V8i. The software provides:

1. A design tool (to simulate natural ventilation, room loads, energy use, plant sizing, CO_2 emissions, and running costs)

2. A compliance tool (i.e., simulation and calculation compliance with ISO and are approved for calculation methods to some British building regulations),

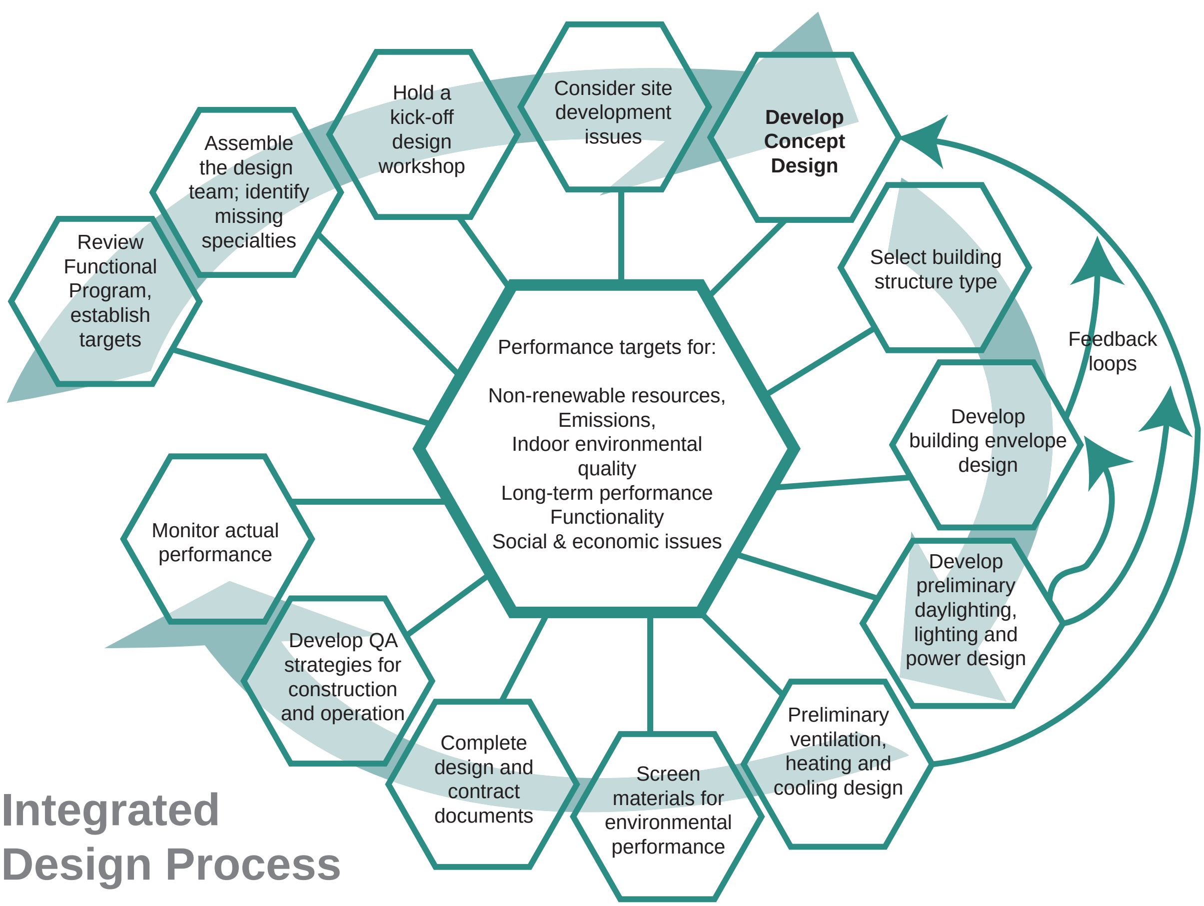
3. A facility management tool (for computing detailed and accurate energy use predictions, energy and cost savings for operational and investment options) (Bentley, 2009).

However, one-stop computational platforms are still at the market exploration stage and have yet been fully or widely implemented in building design practice.

Application requirements

Unlike a conventional linear design process, an integrated design process is characterised by a series of iterative activity loops throughout each design stage: from conceptual to schematic to detailed design and documentation for construction. Each activity loop involves all of the relevant team members to actively interact with one another to create optimal decisions. The assembling of a multidisciplinary team at the start of the project is crucial, and requires a belief in the process and full support from the building developers.

Figure 4.3.2: Integrated design process (Credit: Larsson, 2009)



During the integrated design process, the time taken for the earlier design stages i.e., conceptual and schematic design, is inevitably longer than that of the conventional linear design process. However, this additional time is made up for by the shorter coordinating time at later design stages i.e., detailed design and documentation for construction. Furthermore, due to the involvement of the contractor (builder) in the early design stage, the construction period can be shortened with less coordination, fewer call-backs and variation orders and so on.

Multidisciplinary team members – often including an architect, structural and civil engineer, mechanical and electrical engineer, quantity surveyors and an energy specialist – are required to have a strong team spirit and willingness to listen and cooperate with one another. In this interactive working relationship, the architect's roles are not limited to the generation of built form and spatial layout, but also include the reconciliation and incorporation of ideas/inputs of team members to the building design. The engineers' roles go beyond the provision of systems and solutions to make a design work. Engineers are expected to take initiative to put forward conceptual ideas to contribute to the high performance objective from the early design stages. The quantity surveyor's roles are also extended from the mere construction cost calculation to life cycle analyses and life cycle assessment of building materials and other technological systems to be incorporated into the design. The building developer also has to take a more active role than usual to engage in design workshop, especially those involving in performance goal settings. The high performance goals, life cycle consideration and other design targets should be the ultimate objectives to direct the interaction and working relationships of the team members.

Computational simulations should not just be used at the end of the design stage for verification and presentation purposes. They are particularly useful to simulate the performance of various design strategies and technological systems for comparison. Therefore, computational simulations should be deployed during the integrated design process as a design assisted tool to provide feedback to the team for design improvement and decision making. To be human resources- and time efficient, computational simulation can be applied at the macro level at conceptual design stage to show general/overall building volume for quick outcomes and overall direction. When moving to schematic and detailed design stages, more detailed computational simulations are required to support design improvements and fine tuning.

Implementation status

In the context of sustainable buildings, life cycle and integrated design process have gradually progressed from experimental and ad-hoc applications to mainstream practice in the work of established consultancy practices and building developers. Integrated design process is also adopted as a criterion for pre-qualifying consultancy teams for publicly-funded projects in Canada (Public Works and Government Services Canada, 2011). Clear guidelines on implementing integrated design processes have been established by numerous international organisations and research bodies, such as the International Energy Agency Task 23 and the international initiative for a Sustainable Built Environment.

In recent years, computational simulations have also gained popularity. The main reasons are:

1. The industry has recognised that they contribute to enhancing the environmental performances of buildings and to cost savings (by preventing poor performance leading to costly operational or remedy costs after the buildings are constructed).
2. The development of the technologies has been made more accurate.
3. The development of the technologies has become more user-friendly, compatible and seamlessly transferable among various programs for modelling, drafting, visualisation and simulation. This

shortens modelling and simulation time, which enables timely feedback of simulation outcomes into the design process.

This upward momentum of the global progress for life cycle and integrated design will be further propelled by the upward trend of global operations of many multinational corporations. These established companies (both consultants and building developers) are bringing their established practices in the integrated design and advanced computational assisted design tools beyond their home countries to new building projects in developing and least developed countries.

Feasibility for implementation

The integrated design process does not contain any radically new elements, but integrates a "well-proven approach into a systematic total process" (Larsson, 2004). For example, "the skills and experience of mechanical and electrical engineers, and those of more specialised consultants, can be integrated at the concept design level from the very beginning of the design process" (Larsson, 2005). Experiences from North America and European countries showed that with some initiatives and support from the government for demonstration projects, the integrated design process will subsequently adopted by the building-related professionals due to its proven beneficial outcomes.

The key success factor for the large-scale implementation of the integrated design approach lies in the main players in the building industry changing their mind sets in order to adopt the practice with open minds, initiative and the spirit of teamwork.

In the regions where a life cycle and integrated design process is not a common practice, capacity building is necessary to raise awareness among key players and professionals and to demonstrate how the process unfolds. There is also a need to train a workforce of energy specialists, experts on life cycle assessment and analysis, and experts on using computational simulations as design and decision making tools. In addition, it is also important to collect life cycle information on building materials, products, components, technological systems and establish a comprehensive data bank for life cycle assessment and analysis. These can be carried out in collaboration between local building regulators, research institutes, universities, building product suppliers and other building-related professionals.

Contributions to social, economic and environmental development

The life cycle and integrated design process contributes indirectly to social and environmental sustainability, through providing methodologies and computational tools to deliver high performance buildings. The life cycle assessment and life cycle based decision making also address the scarcity of natural resources, the use of building materials and components efficiently, and end-of-life considerations.

The life cycle approach also contributes to economic development through differentiating true-cost savings from up front construction cost savings that may eventually lead to negative building environmental performances and more spending during a building's operation. The end result is the reduced overall lifecycle costs and social and environmental costs from building construction and operation.

The life cycle and integrated design process contributes indirectly to social development at large, through providing methodologies for stakeholders to deliver high quality buildings. The process strengthens the relationships between building-related professionals by promoting teamwork and positive interaction, leading to better sense of environmental and social responsibility. The process also provides a platform for cross learning, knowledge sharing and innovation/creativity in building a sustainable built environment.

Financial requirements

The life cycle approach and assessment in the integrated design process makes way for cost optimisation based on the entire building lifespan rather than just on the upfront construction cost. Through life cycle analyses, building owners and property developers can better understand the long-term benefits of, and savings from, the integration of energy efficiency design strategies and technologies. These benefits come with a marginal increase in construction cost. Therefore, effective energy efficiency technologies have already been accounted for and are not subject to be removed during cost-cutting exercises, which is usually carried out just before the start of construction.

The life cycle and integrated design process has been proven to help deliver high-performance buildings within or just slightly above the budget estimated at the start of the project (Larsson, 2005). The overall financial requirements for the life cycle and integrated design process are minimal. In fact, the process can be considered as more about re-allocation of budgets among different stages of the entire building lifespan than additional investment requirements. From the building lifespan perspective, the budget shift occurs from using a portion of building operational saving to pay back for the slightly higher consultancy fees incurred during the design stage. The additional consultancy fees are for:

Engaging the engineers, quantity surveyors and energy specialist from the inception of the project, instead of after conceptual and/or schematic design stage.

The life cycle assessment and the use of computational assisted design tools to generate simulations to feedback to the design. This cost component varies according to the availability of such services locally. For example, the costs for life cycle assessment and computational simulation are relatively low in developed countries where the practices are established and there is price-competitiveness between service providers. In this context, many large consultancy practices have the in-house capability to provide the services, and often absorb the extra cost in their overall fee proposal for the project. However, in a local context where specialists on life cycle assessment and computational simulation are rare, the cost for such services can be higher and are often quoted separately in a consultancy contract to the client.

Case study

School in Mayo, Canada:

The 3,400m^2 school is a demonstration project to apply an integrated design process with the support of the Canadian C-2000 Program for Advanced Buildings. The design objectives include the provision of a quality educational environment that is adaptable to broader community needs, high environmental performance, and a fixed budget. Included in the design team were an energy engineer and a design facilitator, who were retained directly by the owner. The concept and principles of integrated design process were introduced to the entire team during the schematic design stage. Under this broad understanding, all team members participated in high-level decision-making process to agree on general design direction. Based on these broad-based directions, specific design issues were solved by the individual disciplines with iterative inter-disciplinary consultation.

During the design process the expectation of creating a high performance building was somewhat tempered by concerns of extra cost and other practical issues. The team also used various computer assisted design tools to assist the decision making process. The tools used included C-2000 process/decision reporting software, DoE for energy simulation, and Superlite for day lighting and lighting analysis. The outcomes were that all project objectives, criteria and budget were met within the tolerance levels of all design team members. In addition, the building achieved high building environmental performance and architectural quality. What was really encouraging was that all design team members were happy with the outcome, and agreed to use the integrated design process in their subsequent projects (IEA Task 23, 2002).

4.4. Building envelope thermal insulation

The technology

Thermal insulation is an important technology to reduce energy consumption in buildings by preventing heat gain/loss through the building envelope. Thermal insulation is a construction material with low thermal conductivity, often less than 0.1W/mK. These materials have "no other purpose than to save energy and protect and provide comfort to occupants" (Insulation and Energy Efficiency: Protecting the Environment and Improving Lives, 2005). Of the many forms, shapes and applications of thermal insulation, this section focuses on those that are commonly used for building envelopes– i.e., floor, walls and roof, and have potential for South-South technology transfer. These include industrial insulation products and the application of natural elements as thermal insulation.

Industrial insulation products are largely classified into three groups – mineral fibre, cellular plastic and plant/animal derived.

Mineral fibre products include rock wool, slag wool and glass wool, which can be sourced from recycled waste. These materials are melted at high temperatures, spun into fibre and then have a binding agent added to form rigid sheets and insulation batts. If removed in appropriate conditions, mineral fibre can be reused and recycled at the end of its life.

Cellular plastic products are oil-derived and include rigid polyurethane, phenlic, expanded polystyrene, and extruded polystyrene. The products are available as loose fill, rigid sheets and foam. In the past, the production process involved ozone depleting agents, such as HCFCs. However, the production process has switched to using neutral hydrocarbons. As such, when sourcing cellular plastic insulation products, it is important to ensure the specified products have production processes that do not use ozone depleting agents. Cellular plastic products can be recycled but it is a cumbersome process. It is more suitable for cellular plastic products to be incinerated for energy recovery at their end of life.

Plant/animal derived products include cellulose fibre, sheep wool, cotton, and flax. These products have low embodied energy, as the materials can be sourced from renewable raw materials. The products are in the form of fibre, batts or compressed board. Their production involves chemical treatment to ensure appropriate properties, such as fire resistance and no vermin infestation. As such, at the end of life, it is difficult to use it for energy recovery through incineration.

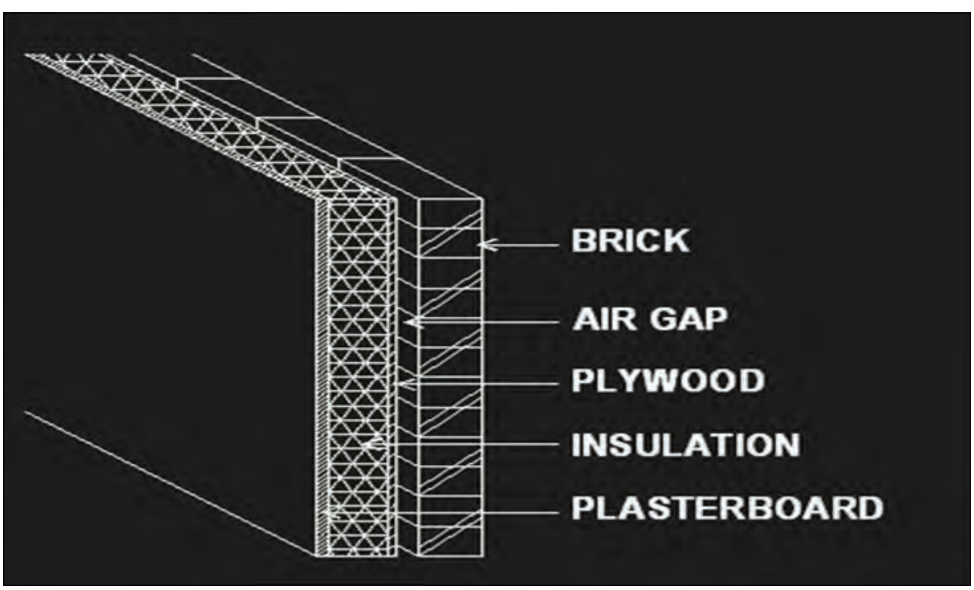
Building envelope thermal insulation is a proven technology that contribute to energy efficient buildings. Two new trends have recently been observed in the development of thermal insulation – the development of phase change materials (PCMs) and innovative use of raw natural elements as thermal insulation.

Phase change materials (PCMs) work based on the latent heat storage principle. “When temperature rises, the temperature of a latent heat store does not increase but the medium changes from one physical state to another, and by this means it stores energy. Therefore the take up of energy cannot be detected by touch. The temperature only rises detectably after a complete change of phase has taken place. When a change takes place, the latent heat involved is equal to the heat of melting or crystallisation of the storage medium. The advantage of PCMs is that large amounts of heat or cold can be stored within small temperature ranges.” (Hausladen et al., 2005).

Because phase changes between solid and liquid, PCMs (such as paraffin) have to be encapsulated prior to use. Paraffin-based PCMs have melting points ranging from 24 to 26^{0}C and are mostly used to prevent heat gain in hot weather conditions (Hausladen et al., 2005). Encapsulated paraffin PCMs are mixed with mortars applied on building envelopes. Used in combination with night cooling strategies (see Section 4.1), PCMs can be effective in preventing heat gain through the building envelope. At present, PCMs are at the research and development, and test bedding stage. PCMs are promising technologies because they are lightweight, easy to apply and blend in well with conventional construction methods.

The second development trend of thermal insulation is the innovative use of raw natural materials as thermal insulation. An example is the use of untreated straw bales as insulation. In order to overcome a fire-hazard issue, straw bales are sandwiched between fire-resistant cladding materials, such as metal-based cladding, or glass panels to create aesthetic effects by making straw bales visible. Another natural element used as thermal insulation is air, which has a thermal conductivity of about 0.025W/mK. Its application is often found in the provision of an air gap in cavity wall construction to enhance thermal insulation performance. Use of air gaps is not sufficient for buildings in temperate regions, but could be sufficient for buildings in mild climate conditions.

Figure 4.4.1: Air gap used in conjunction with insulated timber-brick wall



Application requirements

Building envelope thermal insulation products are used in association with the construction details of floors, walls and roofs/ceilings for new building constructions and for retrofitting existing buildings.

Unlike the straightforward process of incorporating building envelope thermal insulation in new buildings, when retrofitting existing buildings it is crucial to identify suitable locations to include thermal insulation. The key locations are:

1. Roof: to insulate with rigid boards or quilt between or under rafter or joist level.
2. Roof space (in temperate regions): to provide ceiling with rigid insulation-backed plaster boards.
3. Solid masonry or concrete walls: to insulate on the external with rigid boards then covered with water-resistant cladding materials; and to provide internal lining with rigid insulation-backed plaster boards.
4. Cavity walls: to inject with loose-fill fibre; and to provide internal lining with rigid insulation-backed plaster boards.
5. Concrete floor (in temperate regions): to insulate with rigid board under new screed and floor finish.
6. Raised timber floor (in temperate regions): to insulate with rigid board or quilt between or under floor joists (XCO_2, 2002).

For both new construction and retrofitting existing buildings, it is important to understand and provide the conditions for thermal insulation products so that they can achieve their expected performances over their life span.

1. Mineral fibre products are available in batts, rolls and loose. They can be applied in off-site and in-situ construction. Due to the open structure, the products are air and vapour permeable, which can reduce their thermal insulation performance. It is, therefore, necessary to provide foil backing and good workmanship to prevent the product from being exposed to vapour and water. This can often result from condensation occurring between the external wall panel/layer and insulation layer, and/or leaking water pipes that are built inside the wall.
2. Cellular plastic products are considered to be long-lasting materials. The products are not susceptible to decay or vermin infestation. Besides rigid sheets, cellular plastic products can be in the form of foam, which is applied to the building envelope through spraying. Spray foam insulation is applied as liquid, using a hose and spray gun. It is a combination of two substances that blend upon contact, and after a few seconds become a thick foam. The insulation can be sprayed after electrical and plumbing services are in place, as it expands during curing, sealing all gaps.
3. Plant/animal derived products are most susceptible to vermin infestation. Although chemical treatment is often provided in the manufacturing process, the chemical treatment can leach out if the products are wet or exposed to high humidity conditions. Preventive measures include provision of backing, good workmanship, and avoid applying the products in wet and moist conditions.

Good detailing and workmanship to prevent air leakage are crucial for all types of building envelope thermal insulation. It is important to pay additional attention to detail, when installing insulation materials at the electrical outlets and wiring inside walls, cutting and shaping the insulation materials to tightly enclose with the wall frame.

Furthermore, as an overall quality control measure for building in extreme climatic conditions, it is recommended to have building envelope commissioning with attention paid to thermal insulation, especially in larger-scale buildings.

Implementation status and market penetration

Building envelope thermal insulation products have been widely used in temperate regions. In many developed and industrialised countries, thermal insulation is a regulatory requirement for energy efficiency and occupant health purposes, which provide a fairly constant market for the thermal insulation manufacturers. The market for building fabric thermal insulation products is not as large in hot and humid tropical regions, where natural ventilation, not air-tightness, is a more appropriate strategy for thermal comfort. In this context the use of thermal insulation is not extensive, and the use of an air gap in the cavity wall for the west facing façade to prevent heat gain from hot afternoon sun is found to be sufficient. Roof insulation, however, is applicable in all climate regions, including the hot tropical bell. In the Caribbean, for example, roof insulation has generally been accepted as a “proven energy conservation solution” with mineral (glass) fibre generally the lead product (Escalante, 2007).

Feasibility for implementation

In developed and industrialised countries, building codes include requirements to safeguard minimum acceptable insulation levels for building envelopes, and thus provide the opportunity for deploying the application of thermal insulation technologies. However, this is usually not the case in many developing countries, especially least developing countries and remote rural areas. Therefore, a critical factor leading to large scale implementation of thermal insulation in these countries is to put in place supporting policies, both incentive and mandatory measures.

In addition, the cellular plastic production process mentioned earlier involved the use of ozone depleting agents, such as HCFCs, which have switched to using neutral hydrocarbons. When sourcing cellular plastic insulation products, it is important to ensure that the specified products with production process are not associated with ozone depleting agents. It is more effective if local regulations are in place to ban products with production processes associated with ozone depleting agents.

The application requirements of most building envelope thermal insulation products include appropriate detailed design, good workmanship and appropriate product selection, handling and installation methods. Therefore, capacity building, such as workshops to train design professionals and construction work forces in these areas are required.

Contributions to social, economic and environmental development

The primary contribution of building envelope thermal insulation is to provide thermal comfort to its occupants. This supports healthy living environments and better productivity at workplaces.

Thermal insulation reduces unwanted heat loss or heat gain through a building envelope. This, in turn, reduces energy demand for cooling and heating of buildings, and thus is a mitigation measure to reduce GHG emissions.

Large-scale implementation of thermal insulation has also been proven to be an economic stimulus. In the European region alone, there were nearly 12,000 companies, with a total of 400,000 employees, operating in the value stream derived from cellular plastic products (ISOPA &Polyurethanes, 2009). There are ample business and job creation opportunities for developing countries, if successful North-South and South-South transfer programmes for building envelope thermal insulation are in place.

Financial requirements

Financial requirement for building envelope thermal insulation includes the costs of the products and their installation.

The product and installation costs of thermal insulation are computed based on per unit of area and per unit of thermal conductivity value. The installation cost for loose fill products are lower than that of other insulation products, because it is easy to install. However, due to the lack of additional protection from moisture and vermin infestation, long-term durability is a consideration.

Maintenance costs for thermal insulation products is low and not even required for cellular plastic products. In the case of mineral fibre and plant/animal derived insulation, if the products do not perform as expected due to increased thermal conductivity caused by moisture or vermin infestation, replacement is required.

For naturally-ventilated buildings in mild climatic conditions, roof insulation and west-facing wall insulation are the most effective methods of preventing heat gain through the building envelope, and thus have better return on investment compared to applying insulation to the entire building envelope.

Use of straw bales and air gaps (in cavity walls) incur insignificant cost, except for the thickness of the wall. However, long-term performance is an issue to look out for. In developed and industrialised countries, mineral fibre products are cost competitive compared to cellular plastic and plant/animal derived products. However, in developing countries and rural areas, plant/animal derived products are more cost-effective, because of the higher availability and accessibility of these raw materials. Cellular plastic products are rigid, stable and performed well in the long term. They require the least maintenance cost.

Case study

SOLANOVA, Dunaujvaros, Hungary:

The project was supported by European Commission in 2003 to demonstrate best practice in energy efficient renovation of large existing residential buildings. The demonstration project refurbished a 1970s residential building in Dunaujvaros. The building has retail on the ground floor and 7 floors of 42 dwelling units, and is made of industrially prefabricated concrete panels. Among many energy efficient features, the refurbishment included the application of thermal insulation. These included: 160mm polystyrene wall insulation, 100mm polystyrene cellar ceiling insulation, and 300mm thick extensive green roof for roof insulation. Such thermal insulation application contributes greatly to the final 80% reduction of energy demand for space heating, meeting the target of 30-40kWh/m^2/year. This is a significant improvement, compared to 220 kWh/m^2/year before refurbishment (Hermelink, 2006).

HAMBURG HOUSE, Shanghai EXPO 2010:

The Hamburg House in Shanghai EXPO 2010, Urban Best Practices Area Section, demonstrates German green building design and technologies that are applicable in China. The House was designed and built with super insulation in its envelope, as one of many stringent principles to meet passive house standards. The building's walls and roof were insulated with Neopor® thermal insulation – an innovative product by German company BASF. These insulated panels (with thickness of up to 18cm) are cellular plastic-based insulation products that provide an insulation effect up to 20% higher than conventional expandable polystyrene panels (BASF Asia Pacific, 2010). Construction details and installation workmanship were paid particular attention to, in order to deliver an air-tight building and prevent any thermal bridges through the building envelope. The thermal insulation solution to the building envelope contributed to the house's ultra-low heating energy performance of less than 15 kWh/m^2/year, while maintaining a constant indoor temperature of 25^0C all year round (Lu, 2010).

The House, which is a gift from Hamburg City to Shanghai, is a permanent building at the Expo. The House offers a great source of inspiration in terms of green design strategies and technologies to local building-related professionals. This is a great demonstration of North-South technology transfer, in this case, from Germany to China.

4.5 High performance building façade systems

The technology

The building façade is the interface between the external and internal environments of a building. Therefore, it has a large impact on:

1. Occupants' interface with the surrounding environment
2. Energy efficiency and the indoor environmental quality performance of a building, such as lighting and HVAC electricity loads
3. Peak load to maintain good lighting level and thermal comfort for the occupants.

High performance building façade systems involve selecting and deploying the right materials, advanced technologies, good detailing and installation, all of which must be contextually and functionally appropriate.

Figure 4.5.1: Building façade as interface between external and internal environment of a building

Due to the multiple important roles – i.e., aesthetics, thermal comfort, day lighting quality, visual connection to the outdoor environment, acoustic performance, and energy-related performances – building façades, especially glazing systems, have received much attention in research and development. This results in a wide range of products and technologies available to achieve high performance systems.

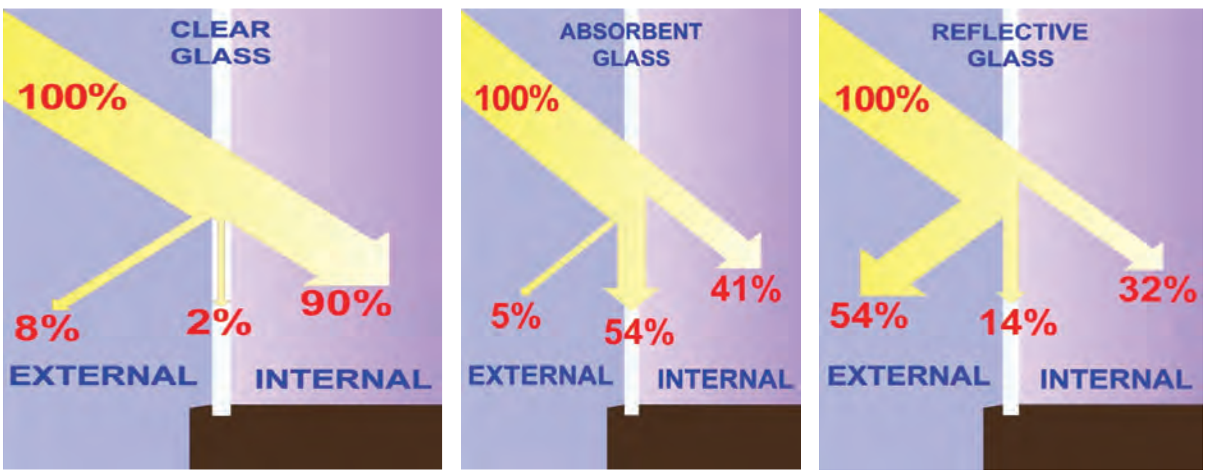
Figure 4.5.2: Wide range of building façades often found in urban fabric, such as Hong Kong in this illustration

Solid walls: it was believed that exterior solid walls with high-mass building materials, have better energy performance. The presumption is primarily based on the shifting of peak load conditions or in an reduction in overall heat gain/loss. However, these presumptions have been challenged by recent technology development in material science and thermodynamics – e.g., phase change materials. At present, there are a wide range of high performance solid wall systems – e.g., from cavity insulated walls (150-250mm thick) to composite panels (with insulation materials integrated and thickness as low as 75mm).

To create solid walls with better thermal performance that are thinner, 'cool paints' have recently been developed. Compared to conventional exterior surface, cool paints help significantly reduce heat gain through their high solar reflectivity when applied on building façades. The use of cool paints is feasible in hot climatic regions.

Glazing systems: There is a growing interest in glass materials and detailing technologies that result in glazing systems with a high ability to interrupt heat gain/loss while allowing maximum visible light transmission. Figure 4.5.2 illustrates the various glazing systems with their respective light transmissions (the percentage of light transmitted through a glazed panel into an interior space). A recently developed material technology involves applying a thin coat of clear metal oxide on a glass surface to enable a reduction in the release of infra reds, resulting in 'low-emissivity glass'.

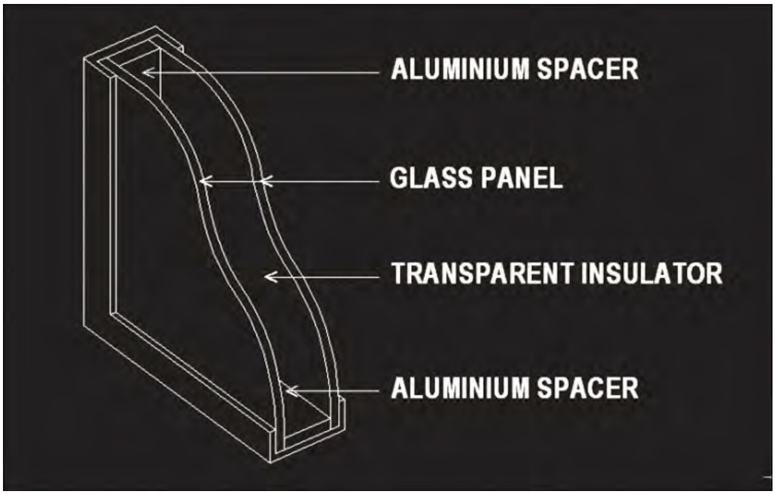
Figure 4.5.3: Light transmissions of various glass types and glazing combinations



Clear glass | Absorbent glass | Reflective glass

Technologies and solutions to enhance the thermal performance of glazing systems include inserting a 'transparent' insulator, e.g., inert gas dry air, vacuum, argon, or krypton, between panes in order to provide a good thermal break to reduce thermal conductance. If the width of the air gap is larger, the insulating property of such a double-glazing system is higher. Triple glazing has also been used to achieve even better thermal performance. The additional advantage of double and triple glazing systems is the excellent acoustic performance, which is an additional benefit for buildings located in noise-polluted environments.

Figure 4.5.4: Double glazing system



Thanks to the availability of different kinds of glass and different combinations, innovative applications have led to the development of smart glazing systems. An example is the glazing system that automatically adjusts its opacity to respond to outdoor lighting conditions, resulting in optimised indoor daylight performance and glare control. Such a system is made possible through the use of photochromic glass technologies.

Figure 4.5.5: Photochromic glass (left) and clear glass (right) in a bright daylight environment

Another example is a 'smart window' with electrified glazing, in which a liquid crystal film is placed between the glazing panes and is controlled by an electrical field to align the crystals so that the window can become clear, or misalign the crystals so that the window can become frosted (Liebard et al., 2010). Current research and development of glazing systems also include the integration of thin film photovoltaic, so that a building façade can offer an additional function of generating electricity. However, this technology is still too costly for large-scale market penetration.

One emerging glazing façade system is the double skin façade, consisting of two glazing skins arranged with a ventilated intermediate cavity of 0.2-2m. For a wider cavity – i.e., 0.6m or more, perforated metal catwalks are usually installed for cleaning and maintenance accessibility. Sun shading devices, such as operable blinds, can be installed within the ventilated cavity. The insulated glazing is used as the inner skin. The ventilation in the cavity space can be natural (e.g., wind and/or buoyancy) or mechanically supported, (such as with an exhaust fan). The ventilated cavity serves as a multi-functional space. Besides being used for maintenance access and sun shading, the cavity inlet/outlet can be closed during a cold winter as an additional insulation layer. The cavity can also be used to preheat fresh air intake, before it is supplied to the air handling unit. During a hot summer, natural ventilation can be allowed in to extract the heated air in the cavity. (Liebard et al., 2010).

Application requirements

Being contextually appropriate is an prerequisite for high performance façade systems– i.e., designing with local climatic conditions, solar orientation, prevailing wind direction, view opportunity, safety consideration, acoustics, nature of occupancy, and so on. "Since climate and occupant needs are dynamic variables, high performance building façade solution must have the ability to respond and adapt to these variable exterior conditions and to changing occupant needs" (LBNL, 2006). Following are the key application requirements:

Wall to window ratio: is a simple rule for high performance building façade design in response to climatic condition and solar orientation. In temperate climatic regions, it is rational to have a low wall-to-window ratio, as the system will allow daylight to penetrate deep into a building's internal space and sunlight accessibility during cold winter months. In hot climatic regions, it is less sensible to have a low wall-to-window ratio as sunlight is ample, sky illumination is high, and window/glazing areas are the weak areas for building heat gain. Following the same principle, a high wall-to-window ratio on a west facing façade offers better thermal performance. This is due to the fact that hot afternoon sunlight and radiation are kept away from building's interior spaces.

Integration of sun shading devices: is essential for glazing systems or glazing areas that are exposed to sunlight. Sun shading devices keep direct sunlight from shining on glazing surfaces, enhance the shading co-efficiency of façades, and result in less thermal transmission through the façade system.

Figure 4.5.6: Sun shading devices integrated with traditional motif as architectural design expression for the Malaysian Ministry of Finance building in Putrajaya, Malaysia

Air-tight but operable: concern about thermal transmittance through building façades has led to the call for air-tight construction. On the other hand, air-tight construction may be detrimental to other building environmental performances, such as natural ventilation and the building's ability to continue operating during electricity black-outs or HVAC malfunctions. Furthermore, air-tight construction has recently been criticised as a contributing factor to poor indoor air quality and sick building syndrome (Passarelli, 2009). In order to mitigate these issues, it is best to provide operable window/glazed panels as part of an air-tight façade system, giving occupants some level of control. For example, high performance double or triple-glazed operable windows.

Figure 4.5.7: Double glazed operable window

Night-time ventilation can be used in double skin façades due to the additional weather protection of the two skin layers and the cavity. It is applicable in hot climatic regions, in summer months in temperate regions and in commercial buildings, which are pre-cooled during the night using natural ventilation. This way, the indoor temperatures will be lower during the early morning hours, reducing the need for and cooling load of air-conditioning (Poirazis, 2006).

Condensation on double-glazing systems. There are three common types of condensation on double-glazing systems: indoor, outdoor and in-between. Indoor condensation is often caused by high internal humidity together with a low outdoor temperature, which cools the inside glazing surface to below the dew point. Condensation forms on the outdoor surface of glass when the glass's temperature drops below the outdoor dew point temperature. The use of low-emissivity glass can restrict heat exchange through the air layer between the two panes of glass, thus the inner glass panel is kept warm, which reduces the chances of indoor condensation forming. At the same time, the outer glass panel is not warmed up due to the heat transmission from the indoor and inner glass panel, which reduces the chances of outdoor condensation forming. Lastly, when condensation is formed on the surfaces facing the air cavity between the two glass panels, it is an indication of leakage in the air cavity, where damp air penetrates in the cavity area and forms condensation. The double-glazing system, in this case, does not perform as intended.

Self-cleaning façade solution titanium dioxide (TiO_2) can be applied on both the solid walls and glazing system. TiO_2 is a type of photo-catalyst. When exposed to sunlight, TiO_2 activates its oxygen molecules to decompose germs, bacteria and organic matter. Therefore, by applying a TiO_2 coating on external façade surfaces – i.e., aluminium claddings, wall tiles, glass, etc., the façade can perform a self-cleaning function. This helps reduce maintenance and cleaning requirements.

Building envelope commissioning. Since the building envelope is one of the most crucial components determining a building's thermal and energy performance, it is worthwhile for larger-scale buildings and buildings with complex façade systems to have building envelope commissioning, to safeguard its workmanship, durability and other environmental performance.

Figure 4.5.8: Building with complex façade combination, found in the Newseum, Washington D.C., USA

Implementation status and market penetration

Simpler forms of high performance façade systems – i.e., cavity insulated walls, cool paints, double glazing and low-emissivity glass – have already become mainstream in many regions around the world. On the other hand, sophisticated façade systems – i.e., triple-glazing systems, double skin façade systems, the use of photochromic glass and electrified glazing, etc. – have a market limited to high-end buildings. Double skin façade systems are costly and usually applied in high-end commercial projects, as they are aesthetically appealing and project an image of transparency and openness that corporations like to convey to the public.

In temperate regions, both high performance solid walls and glazing systems are common practice and have large market penetration. Cavity insulated walls are found in many residential buildings, while composite panels and double skin façade systems are more popular for application in commercial buildings. In hot and arid climatic regions, solid walls with high thermal storage capacity have been widely used. In hot and humid climatic regions near the equator, the use of low thermal transmission façade technologies and air-tight construction are not popular, due to the appropriateness of natural ventilation in these climate conditions.

Figure 4.5.9: Solid wall application in combination with natural ventilation and daylight penetration for a bank in Vinh Long City, Vietnam

Feasibility for implementation

Because a building façade is a necessity for every building, large-scale implementation of high performance building façade systems are highly feasible and rely on:

1. Designing an appropriate wall-to-window ratio as a cost-effective measure for buildings to be sensible to orientation
2. Raising awareness of the importance and benefits of installing high performance building façade systems. The availability of demonstration project (s), from the public or private sectors or both, is particular useful for this purpose. Target groups include building developers, owners, tenants, building-related professionals and the public.

3. Making local building codes and regulations related to thermal and daylight performance of building façade systems more stringent over time. It is important to have performance-based rather than prescription-based codes and regulations, so that there is room for new technology development and innovative design. The limit on maximum Overall Thermal Transfer Value (OTTV) or Envelope Thermal Transfer Value (ETTV) is an example of performance-based regulation to control thermal performances of building façades in many local and national governments, e.g., Malaysia, Singapore, many cities in China.

Figure 4.5.10: Low ETTV building façade made possible with appropriate wall to window ratio, sufficient sun shading devices among other technologies for buildings in the tropics

1. In places where high performance building façade systems are not used or are unfamiliar, it is useful to first carry out research and development to determine material availability and types of façade systems that are appropriate to the local context, including the climatic conditions, patterns and norms of building occupants' behaviours defined by local culture and social values, etc. The findings will serve as baselines for further research and development on designs and the implementation of innovative façade systems. Capacity building is then implemented to upgrade the professional's knowledge and train a workforce with skills for designing, installing, operating and maintaining high performance building façade systems.

Contributions to social, economic and environmental development

High performance building façade systems offer lower heat gain and/or loss and thus reduce the cooling and/or heating loads of a building. This results in electricity saving from HVAC operations and improved thermal comfort for occupants.

Well designed and installed glazing façade systems result in good daylight penetration to a building's internal spaces without creating a glaze effect. This will also contribute to electricity saving by reducing the use of artificial lighting. Glazing façade systems also offer occupants external views, and enhance the quality of the living or working environment.

Figure 4.5.11: Daylight penetration through a high performance glazing façade system

Applying a self-cleaning façade solution on the external surface of building façade systems means cleaning is required less frequently. This translates to savings in water and maintenance costs.

Coupling air-tight construction with operable high performance façade systems provides occupants some level of control, enhances indoor air quality, reduces sick building syndrome, improves occupant health, and contributes to occupants' productivity in commercial buildings.

Financial requirements

Because a building façade is a necessity component of a building, the financial requirements depend on the choice of façade system. For example, in general, the cost of a solid wall is lower than that of a glazing system. However, this may not be true for high-end light-weight and super-insulated sandwich panel claddings (typically consisting of two aluminium skins with a mineral wool core), which cost between S$300-S$450/m^2 in Singapore (DLS, 2009). This is roughly double the cost of a double glazing system with low-emissivity glass, which ranges from S$180/$m^2$-S$200/m^2 (DLS, 2009).

Similarly, building façades with large glazing areas of more sophisticated systems – such as double skin façades, triple glazing operable systems, photochromic glazing, and electrified glazing, require very high investment costs. The figure can be double or triple that of a building façade with a large wall to window ratio and low-emissivity glass.

Maintenance and cleaning costs of glazing systems are higher compared to that of solid walls. An upfront investment to apply a TiO_2 coating on the external surface of façade systems can help reduce maintenance and cleaning costs, especially for glazing systems.

Case study

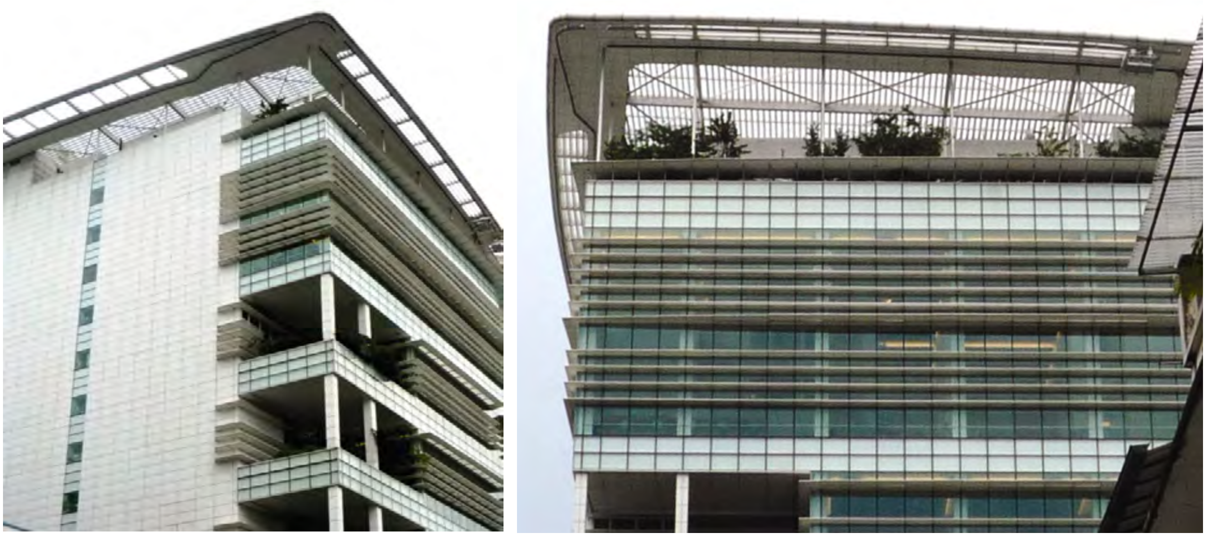
Securities Commission, Kuala Lumpur, Malaysia:

The building is an 8-storey office building with public facilities and has an air-conditioned area of 48,500m^2. The building has a double skin façade and a ventilated cavity. The outer skin glazing system includes low-emissivity green tinted 12mm thick glass. The internal skin comprises 8mm of green tinted glass and automatic perforated roller blinds. The 800mm cavity space between the two skins is accessible for maintenance with the support of horizontal steel grating. The horizontal steel grating is designed to act as a sun shading device for the immediate area below the inner glazing skin. The double skin façade system provides not only a climatic buffer to external hot temperatures, but also offers views to external environments while preventing noise pollution from the surrounding highways. The double skin façade system contributes to the low air-conditional load. The building won the 2001 Asian Energy Award.

National Library Building, Singapore:

The building is a 16-storey library with 3-level basement. It has a gross floor area of 58,783m^2 housing the library, drama centre, education centre and spaces for a variety of public activities. The building was designed with a bioclimatic approach. Its high performance façade is a result of holistic design principles, taking into consideration orientation, wall-to-window ratio, selection of façade systems and sun shading devices. Firstly, the building is oriented to maximise the more ideal north-south orientation. Secondly, for façades subject to strong afternoon sun, a large wall to window ratio is applied, e.g., 93.5% for north-west façade. Thirdly, the building envelope is designed to minimise cooling load. A low-e double glazing system is used for two-thirds of the glazing area, which is exposed directly to strong sun. Furthermore, sun shading devices with appropriate depth are deployed to cut down sunlight penetration through the glazing area to reduce heat gain through the envelope. The result is a glazing system with maximum transparency and minimum glare.

Figure 4.5.12: Low ETTV façade of the National Library Building in Singapore is made possible with double glazing, appropriate wall to window ratio and sufficient sun shading devices



4.6 Daylight harnessing technologies

The technology

Daylight harnessing technologies are applied to bring diffused daylight into the building interior. There are many available methods and technologies available to harness daylight and this section covers three selective technologies, which are commonly found in good practice and yet highly applicable in developing countries. They are light shelves, light pipes and skylights. They can be deployed independently or in combination, depending on the building's configuration and functions.

Light shelves. Light shelves in their simplest form, are specially-designed sun-shading devices, placed on the upper part of windows/glazing façades above eye level. While the natural lighting conditions under light shelves near the window is saturated and glare is circumvented, diffused daylight is reflected on the top of the light shelves to the ceiling area (near the window) and further reflected into the interior spaces. To be efficient, the top surface of light shelves is often painted with a bright colour, or have reflective materials attached, e.g., reflective stainless steel, or even mirrors.

Skylights. Skylights are often located on the upper horizontal plane of buildings, filtering and bringing natural lighting into the building from the roof or any horizontal plane of buildings with good exposure to daylight.

Light pipes. This feature consists of an external transparent dome, a reflecting metal pipe and a diffuser to be installed on ceiling. The dome collects and magnifies external daylight, which is transmitted through the internal reflective metal pipe to the diffuser, which in turn distributes the diffused daylight to the internal space below.

Figure 4.6.1: Light shelf, skylight and light pipe

Light shelf Skylight Light pipe

Stage of development

These three daylight harnessing technologies are proven technologies. The advanced development moves from static features to operable, intelligently-controlled and longer light transmitting distances.

Light shelves. Static light shelves are usually fixed sun shading devices. They are proven technologies and have been widely applied. Movable light shelves are mechanically controlled or sensor-controlled to track the sun angles at different time of day and different seasons of the year. This is designed to allow diffused daylight to enter the building's interior, while safeguarding the areas near windows from undesirable direct and hot summer sunlight and glare issues.

Skylights. Skylights consist of glazing (often insulated) supported by aluminium frames. Skylights can be considered as roofs and are therefore exposed to outdoor weather conditions, such as intensive sunlight and a large volume of rainwater. However, thanks to its long history of use, the technology has overcome the problem of water leakage and hail damage, rain-noise and other thermal-related issues. State of the art development includes the use of electrified glazing and external and an internal lighting sensor to control the quantity and quality of natural lighting entering the building's interior. Advanced skylights incorporate heliostat panels, which track sunlight to enhance lighting performance. Early and late in the day when the sun is low in the horizon, the heliostat aligns with the position of the sun to capture and reflect light through the skylight. Under excessive sunlight conditions, heliostat panels can be positioned to block the sun's rays, and reflect diffused light using reflective material at the back of each reflector panel.

Light pipes. The key objective and advantage of light pipes is to collect sunlight/daylight with a small roof-occupied area, and transmit the magnified light into the building interior. State-of-the-art light pipes use fibre optics to reduce light loss in transmission and to transmit these over long distances (e.g., multiple floors).

Application requirements

Daylight harnessing technologies are suitable for application in all climatic regions. Their contributions can be more impactful in temperate regions where daylight hours are short during cold winter. In terms of functional spaces, these technologies are more suitable for areas where some degrees of fluctuation in illumination intensity are less noticeable and acceptable to the occupants, such as public spaces, atria, retailing areas, carparks, etc. (BCA, 2007).For functional spaces that require more constant lighting conditions, such as laboratories and office spaces, daylight harnessing technologies can be deployed in tandem with artificial lighting to reduce lighting energy demand.

In order to enhance the day lighting performance of an internal space, daylight harnessing technologies can be used in conjunction with high reflectance values for room surfaces. As a rule of thumb, reflectance of walls is above 50%, and that of ceilings is 80% or higher (Ander, 2008). As lighting reflective materials and glazing are sensitive to dirt (which can reduce their performance dramatically) regular maintenance and cleaning are required.

Figure 4.6.2: Reflective interior finishes enhancing day lighting performance in Zuoying Station, Kaohsiung City, Taiwan

Light shelves can take various forms and be installed in various positions in the façade. For example, they can be: integrated with sun shading devices outside and in front of the façade; diffusive reflective blinds in between space of double glazing façade systems; or be inside the room. If installed externally, light shelves' materials and configurations should be designed to avoid creating glare for neighbouring buildings. It is also important not to maximise the use of light shelves at the expense of other environmental performance. For example, in order not to compromise thermal comfort due to heat gain on hot afternoons, windows and thus light shelves should not be installed on the west-facing façade.

Figure 4.6.3: Diffusive reflective blinds installed within a double glazing façade system

Skylights are most appropriate for temperate regions, where winter daylight hours are short and heat gain in summer is less severe compared to hot climatic regions. The technologies are often considered inappropriate in hot climatic regions, due to the fact that skylights bring both sunlight and heat into a building's interior spaces. However, if strategically designed, placed in the shaded roof areas, and a double-glazing system is used, skylights can provide intended benefits to energy efficient buildings.

Figure 4.6.4: Skylights allowing daylight into the interior of Changi Airport Terminal 3, Singapore

Light pipes are suitable for all climatic conditions due to new technology that overcomes many shortcomings of skylights. Firstly, due to its narrow and compact size, light pipes can economically address the heat gain and potential water leakage issues found in skylights. Secondly, light pipes are also less prone to break. Furthermore, light pipes do not provide a visual connection between the interior and external environment, and thus are preferred for application in high security and private areas.

Implementation status and market penetration

Light shelves and skylights have been widely used in developed and industrialised countries. They are often referred to as good design practice, and are well-liked by both design professionals and building users, due to the psychosomatic benefits associated with natural light in the building. On the other hand, light pipes have a low market penetration status. This is because they are a relatively new technology, have a mechanical appearance, and are often seen as an add-on feature by building developers. They are often removed in value engineering, or cost-cutting exercises during the later stage of design development, and do not end up being implemented.

All three daylight harnessing technologies have high market potential in developing countries. The technologies have a high level of acceptance, because the principle of bringing natural light into building interiors can be found in most traditional building methods around the world.

From the climatic influence viewpoint, the high potential market for skylights is in temperate climate regions, due to the fact that skylights can bring large amounts of natural daylight to large interior spaces during a long winter with short sunlight hours. Likewise, light shelves have high potential in tropical and sub-tropical regions, where they can deliver daylight deep into a building's internal spaces while preventing glare for internal areas near windows. Light pipes, from a functional viewpoint, have a potential market in urbanised areas, where light pipes can take up small amount of roof space and transmit light through several floors.

Feasibility for implementation

Because daylight harnessing technologies have been in the market for a long time, the technical aspect of their implementation can be supported by most markets and regions. Their widespread implementation requires institutional support, including appropriate regulations by local authorities regarding planning, building and construction. These regulations should include but are not limited to:

1. Adequate spacing between buildings in according to building height
2. Safety aspects related to the installation of daylight harnessing technologies
3. Preventing over-glaring and direct reflection to the immediate neighbours of the buildings with light shelves.

It is also very helpful if local building codes (standards) are accompanied by guidelines on day lighting design and methodology for day lighting computation, such as the Indian Standards-SP-41 (Bureau of Indian Standards, 1987).

In regions where daylight harnessing technologies are not commonly used, both research and development as well as capacity building for the local building and construction professionals are required prior to large scale deployment of the technologies. Research and development sets the platform for local data collection and local technology development, especially in the areas of local solar illumination and estimating daylight availability. This data will inform practitioners of the most suitable daylight harnessing technologies and system designs for large scale implementation.

Capacity building is also required in the area of design and analysis tools for designers (e.g., hand drawing methods, computer simulation of day lighting design, as well as its impacts on building thermal performance), installation techniques for local construction workers, and maintenance procedures for building owners and facility management personnel.

Contribution to social, economic and environmental development

Daylight harnessing technologies help reduce energy consumption by reducing artificial lighting requirements and thus the heat generation from artificial lighting. The US Green Building Council (2008) estimates that a 50 to 80% reduction in lighting energy load can be achieved from a well-designed daylight-lit building (USGBC et al., 1996). In the tropical city of Bangkok, daylight potential is high and is suggested that it can suffice for 95% of the occupancy period of a typical office building if it is well designed (Tanachaikhan et al., 2009). Such energy saving will help to reduce the operational cost for the building owner, as well as GHG emissions.

In addition to the above mitigation potential, daylight harnessing technologies offer building occupants a connection to dynamic temporal outdoor illumination. Such improved natural light provision offers positive psychological effects to building occupants, and "has a great influence on the user's ability to perform at work and feeling of wellbeing, leading to an increase in productivity" (Hausladen et al., 2005).

With the above contributions, daylight harnessing technologies are not only a mitigation source with good economic sense, but also contribute positively to building occupants' well-being.

Financial requirements

Products and installation costs vary in accordance to the daylight harnessing technologies, design configurations, types of materials (e.g., anodised aluminium frame, powder coated aluminium frame, timber frame, glass, etc,) and quantity of materials used.

External static light shelves can be considered the most cost competitive technology, due to the simplicity of the technology and that they can also act as sun shading devices. In their simplest form, light shelves only require the selection of appropriate reflective materials to bounce daylight into the building interior. Skylights are more costly due to their complicated construction methods and stringent material selection to address safety and water leakage issues. Light pipes are pre-designed and ready-to-use products, therefore the product prices are more predictable. In Eastern Europe, for example, the prices of a light pipes can range from about US$150/each at the lower end to over US$600/each, plus installation costs.

For all three daylight harnessing technologies, regular cleaning is required. This is particularly so in more dusty environments, where maintenance should be carried out at shorter intervals, so that the technologies can meet their expected performance.

Case study

Pusat Tenaga Malaysia's zero energy office (ZEO) building, located 40km south of Kuala Lumpur, demonstrates the deployment of daylight harnessing technologies very well. While light shelves with mirror tops are deployed on the building façade, the central atrium is lit with daylight by a large integrated solar-cell skylight, and deep internal office floors are lit by light pipe/coup. When daylight drops to an insufficient level for office tasks, lighting condition in workstations is then supplemented by an intelligent energy efficient artificial lighting system and a LED task light. With a holistic design solution to integrate all three daylight harnessing technologies, daylight becomes the main lighting source (targeted at 100%) during daytime, and contributes greatly to the building's net zero energy performance.

Figure 4.6.5: Light shelf, skylight and light pipe in Pusat Tenaga Malaysia's zero energy office

Light shelves, top clad with mirror Skylight over the central atrium Office space lit with light shelves (on the right) and light pipe through ceiling (on the left)

4.7 Highly efficient heating, ventilation & air conditioning systems

The technology

Heating, ventilation and air conditioning (HVAC) systems supply fresh air and condition the indoor air temperature and humidity of a building. HVAC is reported as the key energy user (37%) in US buildings (WBCSD, 2008), accounting for 59% of the energy used in China commercial buildings in 2000 (Levine et al., 2007). Therefore, HVAC is a key component of climate change mitigation potential in the building sector.

HVAC systems normally consist of components to supply, filter, heat, cool and distribute the conditioned air into targeted interior spaces. In an HVAC system, the principle: 'the whole is more than the sum of its parts' is applied. This means the high-efficiency of one component can operate at expense of the others. As an example, take two categories of HVAC systems: high- and low-pressure systems. High-pressure systems allow high-velocity air to flow through the duct system in the range of 10 to 25m/s. These systems have smaller ducts and require less space to house the duct system, but require more fan energy to drive the air. The high-velocity airflow has its speed reduced at the terminal outlets to avoid a strong flow of air that creates discomfort for occupants, known as draught. Low-pressure systems conduct supply airflow at low velocities and require larger duct spaces. In this case, HVAC system efficiency depends on the selection and integration of the key components that suit a specific building and its context.

As highlighted, highly efficient HVAC systems can be achieved through the best-fit integration of HVAC's key components. These key components, or sub-systems, are heating, cooling and ventilation. These components have constantly undergone technological upgrades to improve their efficiency.

Heating systems:

Boilers are usually used to generate hot water or steam using coal, diesel or natural gas. Conventional boilers – i.e., cast iron boilers or water-tube steel boilers – have combustion efficiencies between 78 to 86%. The newer generation of condensing boilers achieve up to 96% combustion efficiency. Condensing boilers are often fired with natural gas – a less polluting energy source. They are more efficient at removing the heat from the flue gases, and can be operated more efficiently than the conventional boilers at part-load (Graham, 2009).

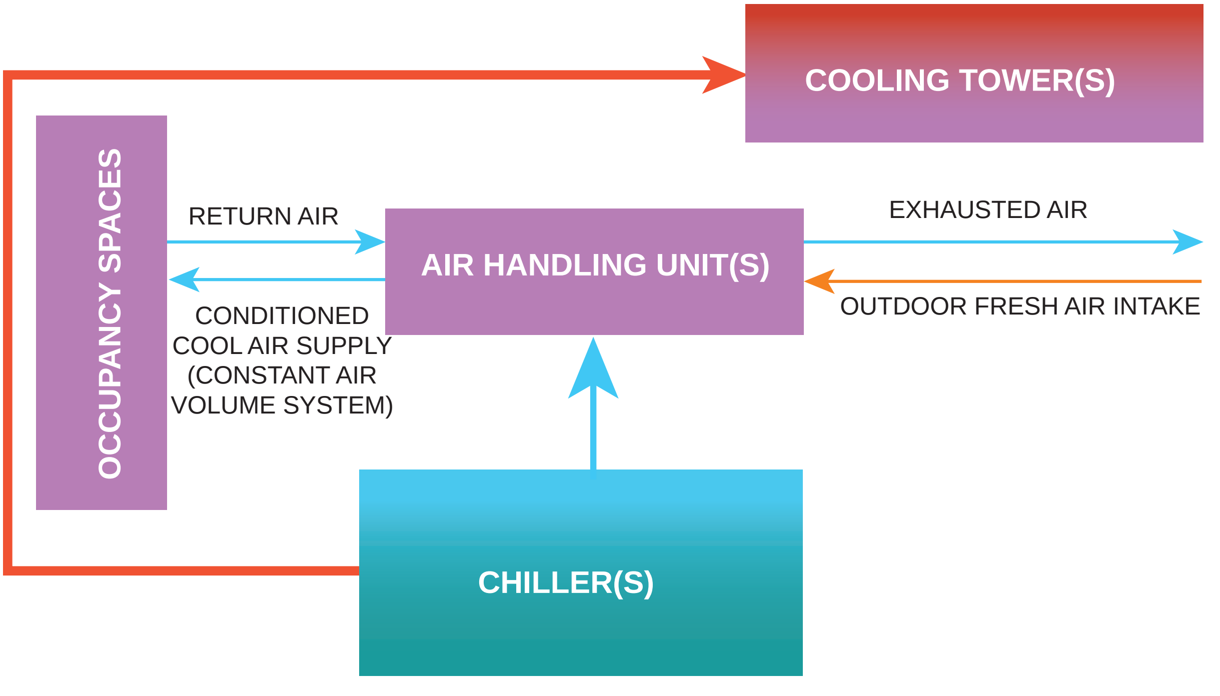
Heat pump technologies are developed as an alternative to fossil-fuel-based boilers. The technologies extract heat from warmer underground earth, air or sub-surface water during winter months, in temperate regions, to condition the temperature for indoor usage. Reversing the above cycle during summer months, a heat pump extracts heat from indoors to outdoors to provide cooler indoor temperature.

Cooling systems:

Chillers are used to produce cool water, which is then pumped to air handling units to cool the air. Chillers use either mechanical compression or an absorption process. Among mechanical compression chillers, centrifugal chillers are the most efficient for large-capacity operation, such as in large office buildings or retail complexes. Absorption chillers, on the other hand, produce cool water through heat sources, i.e., gas burners or high-temperature water, instead of using electricity to run compressors. In this way, absorption chillers enable the use of hot water tapped from solar thermal systems for air conditioning.

Condensers are required in chiller systems, which reject heat to the environment and allow chillers to continuously remove heat from indoor conditioned spaces. They can be air-cooled or water-cooled. Air-cooled condensers are used for small-scale application, whereas water-cooled condensers are more costly but much more efficient for large-scale systems and are usually seen in large building complexes. Water-cooled condensers require cooling towers, usually located on the rooftops of buildings, to reject heat from condensers into the environment.

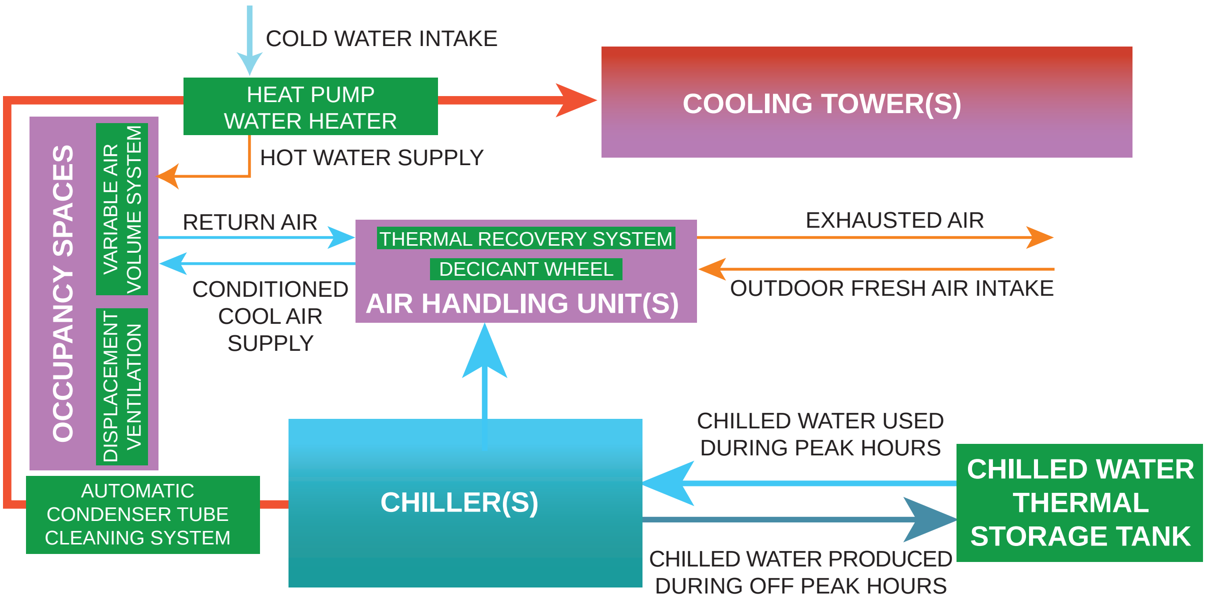
Figure 4.7.1: Diagram of a typical conventional cooling and ventilation system



Energy recovery installed in the mechanical ventilation system can help save energy. Air conditioned air fume cupboards can be use to cool incoming replaced air through a heat exchanger instead of being discharged directly outdoors. This can pre-cool incoming replaced air to a temperature of approximately 25˚C in tropical regions, thus reducing energy use for cooling (BCA, 2007). Desiccant wheels have the ability to dehumidify the air while carrying out heat exchange, and are also suitable for hot and humid regions in the tropical belt.

An automatic condenser tube cleaning system allows water-cooled heat exchange type chillers to maintain good performance through constant cleaning of the condenser tubes. The system circulates cleaning sponge balls into the condenser tubes, which are then rinsed in a ball receptacle through swirling motions (Hydroball, 2007).

Figure 4.7.2: Diagram of a typical energy efficiency cooling and ventilation system



Ventilation systems:

Variable Air Volume (VAV) systems vary the amount of air intake to a room while keeping the air temperature constant. This strategy is different from the Constant Air Volume (CAV) systems, which supply a constant rate of air intake while varying the temperature of the supply air. As the supply air is centrally cooled to meet the coldest temperature demand, CAV systems may lead to rooms/zones with a lower temperature demand to be over-cooled resulting in energy being wasted. VAV, instead, allows for better room temperature control, and when used with variable speed drive fans, can save up to 15% on energy use (BCA, 2007).

Displacement ventilation uses the principle that 'warm air rises' to provide ventilation in an air conditioned room. Displacement ventilation typically supplies conditioned air from a raised floor system through a series of adjustable floor-mounted registers. The room's air is stratified: lower temperature air stays in the bottom portion of the room (where people are located and cool air is needed) and high temperature air rises towards the ceiling (Graham, 2009). As a result, displacement ventilation helps reduce energy used for higher fan speed to drive cooled air down from the ceiling like conventional ceiling-mounted air outlets do. Furthermore, displacement ventilation can provide the same level of comfort with a significantly higher supply air temperature, i.e., about 18^{0}C compared with about 13^{0}C in a conventional ventilation system (Levine et al., 2007).

Figure 4.7.3: Displacement ventilation

Application requirements

Highly efficient HVAC systems require great efforts during the design stage for coordination, selection, and design for best fit integration of HVAC components to be suitable for a specific context and unique parameters of a building.

Zone control is the first and easiest strategy for a highly efficient HVAC (including heating and cooling) system. Wherever possible, spaces/rooms in a building should be divided into smaller enclosed rooms, each equipped with own thermostat, motorised damper and control system. This way, users are able to adjust the room temperature independently to suit their thermal comfort level. It is estimated that the application of zone control in a commercial building in Singapore can cut energy consumption by up to 25% (DLS, 2009).

Proper sizing of components. This is a simple concept but is hard to achieve. The conventional practice of mechanical and electrical engineers is to base sizing on the worst-case scenario for simultaneous load demands e.g., worst-case weather, lighting loads, equipment's load, full occupancy and so on. However, in recent years, empirical data from building science research has proven that oversized equipment operates less efficiently and costs more. It is suggested that it is better to "plan for expansion, but do not size it." (Graham, 2009)

Location of fresh air intake has to be carefully considered and placed away from any (potential) pollution and odour, such as from basement garage floor or directly facing garbage collection points. It is also not desirable to locate an air intake close to an air exhaust outlet. In this way, incoming air to the HVAC systems is fresh and of good quality.

Shifting peak load in cooling systems to utilise off-peak electricity at night or solar energy during the day to generate thermal energy, e.g., in the form of ice or chilled water. This thermal energy will be stored and used for air conditioning during peak cooling/heating times. This will result in lower electricity peak demand and will reduce energy costs.

Heat delivery in heating systems to the occupancy spaces includes two common methods, hydronic heat and forced hot air. In a hydronic heat system, heated water from a boiler is pumped through pipes running in floor slabs and/or walls around the building. Heat is radiated from the hot water to warm the occupancy spaces. The advantages of these systems is quietness, and that heat can be distributed evenly.

In forced hot air systems, heated water is circulated through a fan-coil unit to warm the heat exchanger. Air from inside the building is then circulated and is passed through the warm heat exchanger. Finally, the warmed air is delivered to the occupancy space (s). The warm air outlets are recommended to be located on the floor or lower wall of the occupancy spaces. Ceiling mounted outlets work against the natural buoyancy of warm air, and thus requires additional energy for higher fan speeds to drive the warm air down to the human level.

Implementation status and market penetration

Global demand for general HVAC equipment has been reported to increase by 6.2% per year up to 2010 to US$93.2 billion. In the Asia-Pacific region, the demand growth will outpace the global average with China's market growth contributing to about 40% of global demand growth (Freedonia, 2010).

With the increase in construction expenditures and higher per-capita income, India's high HVAC market demand is also projected to grow at a faster pace than the global average. With growing worldwide demand, highly efficient HVAC systems stand to enjoy good market prospects. Moreover, rising oil and electricity prices, coupled with wider public awareness of being energy efficient, will help to push the demand toward the highly efficient section of the market.

The IPCC also highlights the trend of higher demand for individual apartment and home air conditioning in developing countries, reaching even higher levels in developed countries (Levine et al., 2007). This trend is evident in the production trends of such air conditioning units – from 35.8 million units in 1998 to 45.4 million units in 2001, which is an increase of 26% (IPCC/TEAP, 2005).

Although higher investment costs are required, the market penetration of absorption chillers is estimated to be one-fifth for China's central HVAC system market. This is much higher than that in the US, which is about 1%. This is because in China, many buildings and factories already have diesel generators and fuel storage tanks to address blackouts. Therefore, it makes more economic sense for building owners to install absorption chillers than to install those that run on electricity (Bradsher, 2010).

Displacement ventilation is reported by the IPCC's Fourth Assessment Report to have high take-up rate in Northern Europe, i.e., 50% of the new industrial buildings and 25% of new office buildings in the Scandinavian market. However, the take up rate of displacement ventilation in North America has been much lower, i.e., less than 5% of new buildings.

Feasibility for implementation

Capacity building, local building codes related to HVAC and supporting the growth of energy services companies, ESCOs (see section 4.16) are three key elements to make highly efficient HVAC systems and their sub-systems more feasible for large-scale implementation, especially in the context of developing countries.

As highlighted in the ‘application requirement’ section, one of the major barriers to implementing highly efficient HVAC systems is the installation of oversized systems that result in inefficient part-load most of the time. In order to break the vicious circle created by this conventional practice, training workshops to upgrade professional knowledge will be necessary. Furthermore, well designed demonstration building projects that are equipped with highly efficient HVAC systems and show a proven records of energy saving and good thermal comfort performance, will be a good catalyst.

Setting minimal performances in building codes provides an institutional setting for the design and implementation of more efficient HVAC systems in buildings. An example of good standards is the American Society of Heating, Refrigerating and Air conditioning Engineers (ASHREA), which also provides guidelines on how to achieve highly efficient HVAC design and installation.

As HVAC systems are seen as the main energy-consuming component in buildings, improving the energy performance of HVAC systems is the main business area of many ESCOs. Therefore, supporting the development of ESCOs and energy performance contracting business will indirectly nurture the implementation of highly efficient HVAC systems.

Contributions to social, economic and environmental development

Due to the high percentage of energy consumption, highly efficient HVAC systems contribute to both economic and environmental development. Firstly, they are reported to have the potential of energy saving of 30 to 40% in overall building’s conventional HVAC energy consumption, which contributes greatly to GHG emissions reductions in the building sector. Furthermore, such savings can be translated into significant savings in electricity bills for the building owners and/or tenants. With the right government regulations and support, ESCO businesses could prosper in this area, which in turn stimulate more market demand and the adoption of highly efficient HVAC systems.

Highly efficient HVAC systems deliver cleaner and better quality air to the indoor environment – i.e., through the carefully located fresh air intake, the installation of automatic condenser tube cleaning systems and UVC emitters. This, in turn, contributes to better indoor living and working environments, reduction of sick building syndrome, and better living comfort and productivity.

Financial requirements

As highly efficient HVAC systems can be achieved in many ways, depending on the nature of the buildings, their financial requirements vary. If highly efficient HVAC systems are designed during the design stage, additional investment costs may be minimal in many cases, thanks to that the equipment cost is reduced from proper sizing (instead of oversizing) of the equipment.

Additional investment costs are sometimes required for additional HVAC subsystems for example, from installation of automatic condenser tube cleaning systems, larger piping areas or ice storage systems. In general, the increased investment costs for highly efficient HVAC systems will be recouped from energy savings and reduced maintenance costs. For example, the typical payback period for a system with 30% energy reduction is about 3-5 years in North America (Graham, 2009). The following are some indicative investment costs for highly efficient HVAC sub-systems in Singapore:

1. Absorption chiller with capacity of 1mW costs approximately S$315,000; 2mW costs S$501,000; 3mW costs S$783,000; and 4mW costs about S$1,061,000.

2. A 1.5kW variable speed drive chiller costs approximately S$922, 5kW costs S$1,500, 10kW costs S$2,000, 22kW costs S$3,200, and 30kW motor costs S$3,600. The payback period is about one year or less.

Case study

Ministry of Energy, Water and Communications building, Malaysia:

The building is known as a low energy office (LEO) building and has an air conditioned area of 17,000m^2. The highly efficient air conditioning system is achieved through the integration of the following key sub-systems:

1. Zoning for localised cooling and controllability to meet the variable occupancy patterns and loads required.
2. Variable air volume (VAV) boxes and variable speed drives (VSDs) are installed to support zoning of cooling needs.
3. Room temperature control sensors are also used to better manage the cool air demand.
4. CO_2 sensors are installed to control the amount of fresh air intake to maximise energy performance and indoor air quality.
5. Air based heat recovery wheel is used to cool fresh air intake and reduce cooling load.
6. Electronic air cleaners are used to maintain efficient air filtering system, improve indoor air quality, and reduce energy losses from dust accumulation.

The result is a cooling load of 64 kWh/m^2/year, compared to a conventional building at 120 kwh/m^2/year, which is an energy saving of nearly 50%.

4.8 Efficient lighting systems

The technology

Lighting in is reported to consume as much as 21% of the total energy use in buildings (Levine et al., 2007), and to account for about 17.5% of global electricity use (Pike Research, 2010). A market shift to energy-efficient alternatives would reduce the world's electricity demand for lighting by an estimated 18% (UNEP, 2009). Therefore, efficient lighting systems are one of the most important climate change mitigation measures for the building sector. Efficient lighting technologies include energy efficient lamps, ballasts and light fixtures. The requirements to implement efficient lighting system include incorporating natural daylight, zone control, user-control, and dual lighting circuit systems.

Technologies used in modern artificial lamps to emit light include thermal radiators, discharge lamps, and electro-luminescent radiators. Thermal radiators, such as incandescent and halogen lamps are not energy efficient, in general. Lamps that generate light through thermal radiation require energy to heat a material to a high temperatures in order to give off light. Therefore, in addition to emitting light within visible light range, a large amount of radiation is emitted into the surroundings in the form of heat and radiation in other wavelengths. Discharge lamps (e.g., fluorescent lamps) generate light by means of electrical discharge through gases and vapours. They are more energy efficient than thermal radiator lamps. For example, compact fluorescent lamp (CFL) converts some 25% of the energy to visible light, while an incandescent lamp converts only 5% of the energy consumed into visible light, leaving 95% to be emitted as heat (UNEP, 2009)

Figure 4.8.1: Energy efficient lamps

Fluorescent lamps

LED

Electro-luminescent radiators, used in light-emitting diodes (LED), are also energy efficient. LED relies on a semiconductor circuit to convert electrical current into light. This technology is at least ten times more efficient than incandescent lamps.

Figure 4.8.2: Comparison of commonly used lamps

Type	Lamps	Means of energy discharge	Main applications	Energy efficiency
Thermal radiators	Incandescent	Light, heat and radiation.	Home, office, factories, etc.	NO
	Halogen		Retail, hospitality, etc.	
Discharge lamps	Compact fluorescent lamps	Light by means of electrical discharge through gases and vapours.	Home, office, factories, retails, hospitality, etc.	YES
	T5 and T8			
Electro-luminescent radiators	Light emitting diodes	Convert electrical current into light.	Home, office, factories, retails, hospitality, etc.	

Different lamp types have different characteristics. The selection of energy efficient light should take into consideration the following criteria: high luminous efficacy (lumen/watt), miniaturisation, longer lifespan, use of recyclable materials, and avoiding hazardous substance (DLS, 2009).

In addition to lamps, ballast and luminaries also play a part in energy efficient lighting. Ballasts help to increase energy performance, such as a dimming function. Luminaries are generally made of reflective materials and in the form of lenses, refractors, louvres or blades to enhance light output by reflecting indirect light to brighten an area, such as surrounding walls, or task surfaces.

Energy efficient lamps. There are two groups of commonly used energy efficient lamps: gas-discharge lamps and LED. Gas-discharge lamps are classified into low-pressure lamps and high-pressure lamps. Low pressure lamps are also called fluorescent lamps. The technology includes linear T5/T8 tubes and CFL. Both are advanced technology with highly energy efficient performance, are compact in size and have a long lifespan. CFLs provide good diffuse light and are often used for downlighting and wall lighting. They can also be used for task lighting. High pressure lamps, also known as high-intensity discharge (HID) lamps, are another type of energy-efficient lamps. They are suitable for illuminating large areas and for outdoor applications. HID metal halide lamps, for example, have very high luminous efficacy and replacement life of up to 9,000 operating hours (Hausladen et al., 2005). PAR metal halide lamps with ceramic arc-tube enclosures have good colour rendering and can replace halogen lamps for accent lighting. One disadvantage of HID lamps is that they take longer to start. Therefore, they are more suitable for application in spaces requiring long hours of operation, where they are less frequently switched on and off.

LED lamps emit light in a very narrow spectral band but can produce white light that is good for application in daily life environments, such as homes and offices. White light can be formed by mixing individual LED lamps that emit red, green, and blue array, or coating a blue LED lamp with phosphor (Nelson, 2010). LED lamps have very long lifespan of 40,000 to 100,000 operating hours, depending on the colour. In the earlier stage of development, LED lamps had very limited applications, such as exit signs and decorative applications, due to having poor colour rendering index and poor efficacy. However, LED lamp technologies have been greatly improved, now they can be found in a wide range of applications – from landscaping lighting, task lighting, wall wash lighting, retail use spotlights, to lighting for artworks.

Ballasts help to improve lamp efficacy, increase lamp lifespan and reduce power losses. High frequency electronic ballasts help to improve visual performance and eye fatigue. For example, the frequencies range of 20kHz and above provides high quality, non-flickering lighting that reduces strain to the eyes (Nelson, 2010). Dimming electronic ballasts for fluorescent lamps help to reduce energy consumption when bright lighting is not required, i.e., in the space and at the time when daylight is strong.

Light fixtures help enhance the performance of lighting output, improve distribution, control glare, and further increase energy efficiency. A variety of light fixtures designed to accommodate energy efficient lighting have become available in the retail market and for business uses. Examples of energy efficient light fixture applications are:

1. Recessed downlights offer a round shape to be used with CFL lamps.
2. Linear strip light fixtures are mainly ceiling mounted with or without side reflectors typically used with T8 lamps. It is small in size, low-cost, and easily dimmed. It is most suitable for mechanical rooms, lockers, garages, etc. It can also be used for workplace ceiling lighting.
3. Wall sconces are wall mounted for decorative purposes, and can be used for CFL lamps. They can be used on lobby walls, corridors, formal meeting rooms, etc.
4. Indirect/direct linear light fixtures can be hung under a ceiling or be wall mounted and are usually used with T5s or T8s. In combination with bright ceiling surface, indirect linear light fixtures can provide soft and comfortable visual effect and are easily dimmed. Indirect linear light fixtures are usually applied in high ceiling spaces, such as classrooms.

Figure 4.8.3: Examples of energy efficient light fixtures

Recessed downlight | Linear strip light fixture | Wall sconce | Indirect linear light fixture

Application requirements

A complete energy efficient lighting system includes energy efficient lamps, ballasts and light fixtures. There are at least four main design principles that need to be considered when implementing energy efficient lighting systems.

Use in association with natural daylight. Artificial lighting should be designed and used along with daylight harnessing technologies (see Section 4.7) to reduce energy demand in the first place. For light fittings installed on ceiling areas near windows, spacing for lamps can be further apart. Task lamps can be deployed as supplementary lighting.

Zone control. It is particularly useful to divide spaces of a building into zones of different levels of artificial lighting requirements, and to provide multiple control circuits to facilitate various lighting demand. An example of zone control is to incorporate daylight into zone lighting in corridor or rooms located closed to window areas and installed multiple circuits to enable switching on/off or dimming in response to available daylight.

Figure 4.8.4: Zone control allows the library space near the window tapping on daylight (left), while the space away from the window is illuminated by CFLs

User controllability and motion sensors. This requirement addresses the wiring of lighting in office buildings, especially in open office layout. The conventional application is to provide one circuit to link many (if not all) light fixtures in a large space together with one or two centralised switch points. This type of application wastes energy and reduces light fixtures' lifespan in low occupancy hours. Therefore, providing flexibility for user controllability at individual workspaces or smaller workspace zones can save energy. Motion sensors can also be installed so that lighting can be automatically switched off when there are no occupants in the zone.

Dual lighting circuit system: Such system allows alternate lights to be turned off at times when bright lighting is not critical. The suitable areas for this application include garages, residential complex corridors, and landscaping areas. These areas are used substantially less after midnight. Part of the lights can be turned off to save energy. Research shows that a saving of 30% on lighting electricity consumption can be achieved, and the payback period is as short as about 6 months (BCA, 2007).

Implementation status and market penetration

Energy efficient lighting has been adapted widely, thanks to proven business cases showing its energy saving and return on investment. The Environmental Leader Insight (Sep. 2010) projects that the global market potential for energy efficient lighting is expected to increase from US$13.5 billion to US$32.2 billion from 2010 to 2015, representing a annual growth rate of 19%. It is also projected that the growth will be strongest in commercial lighting from 2010 to 2012, followed by residential lighting from 2012 to 2015. Among the various energy efficient lighting technologies, LED holds significant long-term potential, because LED is at the early stage of market penetration, with costs potentially coming down and with improving technologies leading to wider commercial applications (Pike Research, 2010).

The markets for energy efficient lighting technologies are in both developed and developing countries. In recent years, the markets for energy efficient lighting in developing countries have been growing strongly for three reasons. Firstly, in 2009, the Global Environment Facility, the United Nations Environment Programme and lighting industry partners started Global Market Transformation for Efficient Lighting Project, known as the en.lighten initiative – Efficient Lighting for Emerging and Developing Countries. One of the objectives of the initiative is to phase out incandescent lights worldwide (en.lighten, 2009). The initiative estimates a saving of 409 terawatt hours/year, or 2.3% of global electricity consumption, by replacing all incandescent lamps with CFLs). Secondly, developing countries are implementing programmes to promote CFL, and even distribute them for free. These programmes are often part of rural development strategies, especially in African countries, India and China. Ethiopia's CFL programme, as detailed in the case study below is an example of such programmes. Thirdly, the costs of CFL and LED have been brought down significantly over years. For example, in South Asia countries, the cost of CFL has dropped from an average of US$12 in the mid-90s to an average of US$3-$5 in 2008 (Goswami et al., 2010).

Feasibility for implementation

Energy efficient lighting technologies are among the technologies that are most feasible to implement at a large scale. This is due to their smaller investment cost, easy and straightforward installation, and the fact that they are a necessity for daily life. With such characteristics, energy efficient lighting technologies can be implemented from both bottom-up and top-down approaches. In a bottom-up approach, individual building/house owners can make a decision to adapt and use energy efficient lighting fixtures with a one-time small investment cost, which will be paid back through savings from energy bills. The decision to switch to energy efficient lighting systems from the bottom-up approach can be facilitated by top-down supporting policies, which include:

1. Reducing/removing import tariffs on energy efficient lighting components
2. Initiating energy efficient lighting programs which provide or subsidise energy-efficient lighting
3. Supporting local manufacturers to produce energy efficient lighting components and systems, to further bring down the costs and to create new local jobs
4. Providing public education and campaign programmes to introduce energy efficient lighting technologies and their benefits
5. Providing safe disposal of CFLs at the end of their life due to the mercury used in the lamps. One measure is to establish a CFL recycling plant, which can handle mercury and other environmental safety issues.

Contributions to social, economic and environmental development

Implementing energy efficient lighting technologies brings many benefits to environmental protection, and, energy resource conservation. Energy efficient lamps can substantially reduce GHG emissions from lighting buildings. For example, CFL or LED lamps consume one-fifth (or less) of the energy incandescent lamps require for the same illumination capacity and they are approximately 1,000 times more energy efficient than kerosene lamps (Mills, 2005). In terms of lifespan, compared to incandescent lamps, CFLs last eight times longer with a lifespan of up to 8,000 operating hours (Hausladen et al., 2005). LED lamps last 40-100 times longer with a lifespan of 40,000 to 100,000 operating hours depending on the colour.

Energy efficient lighting technologies also improve health and living conditions for building occupants. In rural areas, such as remote villages in Africa and South Asia, the use of CFL and LED technologies as replacements for kerosene lamps will help improve the lighting quality, provide longer study or work hours and reduce the fire risk from kerosene lamp use. In urban areas, the use of high frequency electronic ballasts helps reduce eyestrain and fatigue, increase productivity in workplaces and provide better quality of life.

In terms of economic development, large-scale implementation of energy efficient lighting in least developing regions/countries could potentially form a critical mass to set up local manufacture for lighting component production. This will help create jobs and upgrade skills of the local workforce, and provide cost effective energy efficient lighting fixtures to the local end-users.

Financial requirements

The major financial requirement for energy efficient lighting technologies is the initial investment to purchase the products and installation. This cost is normally paid back in a short time period. For example, in India, the estimated payback period of replacing an incandescent lamp with CFL is 1.2 years, and that of replacing a kerosene lamp with CFL is less than a year (Bhattacharya & Cropper, 2010). Compared to CFLs, LED lamps require a higher initial investment, but their long lifespan (up to 10 times of CFL) makes up for the high investment cost. As a rule of thumb, the investment cost for LED light is usually paid off within the first year of use. Maintenance costs are negligible during the lifespan of energy efficient lamps and ballasts.

In general, it is expected that the investment cost for efficient lamps will continue to go down from the continuous technologies upgrades, the increase in mass production capacity through increased market demand, and shifting of component manufacturers to developing and least developing countries.

Case study

Ethiopia's CFL programme

Ethiopia's government, with the support from the World Bank, has implemented the initiative to switch from incandescent to CFLs nationwide. The government started with distributing 5 million CFLs for free, in exchange for existing incandescent bulbs. To maximise the impact, the exchange programme ran parallel with a major energy saving awareness campaign. After three months with 2.5 million CFLs distributed, the Ethiopian Electric Power Corporation reported a reduction of 80MW of peak demand, which would have been generated by diesel generators. This translates to a saving of approximately US$100 million created by a US$4 million CFLs distribution programme (World Bank, 2010). The participants benefit from the better lighting quality and lower energy expenses.

4.9 Water efficiency technologies

The technology

The use of water in buildings has an indirect but large contribution to energy and resource consumption. The production and distribution of water for buildings is an energy-intensive activity. Energy is used to purify fresh water sources to a level that is safe for consumption in buildings and to run pumps for cleansing and distribution. In many regions where fresh water is a scarce resource, additional energy is required to extract water from deep underground, to transport water from a long distance, or to operate an energy-intensive desalination plant, etc. Furthermore, transferring wastewater back to the treatment plant requires energy for pumping. At the wastewater treatment plant, electricity is required for wastewater aeration and other treatment systems. It is estimated that 30-40% of the electricity used by mid-sized cities is used to pump water through the distribution system and treat wastewater (Johnson Controls, 2011). Therefore, if we conserve water, we conserve energy.

In brief, water efficiency in buildings has a strong link to energy saving and climate change mitigation. Therefore, water efficiency technologies are discussed in this guidebook as a mitigation option in the building sector.

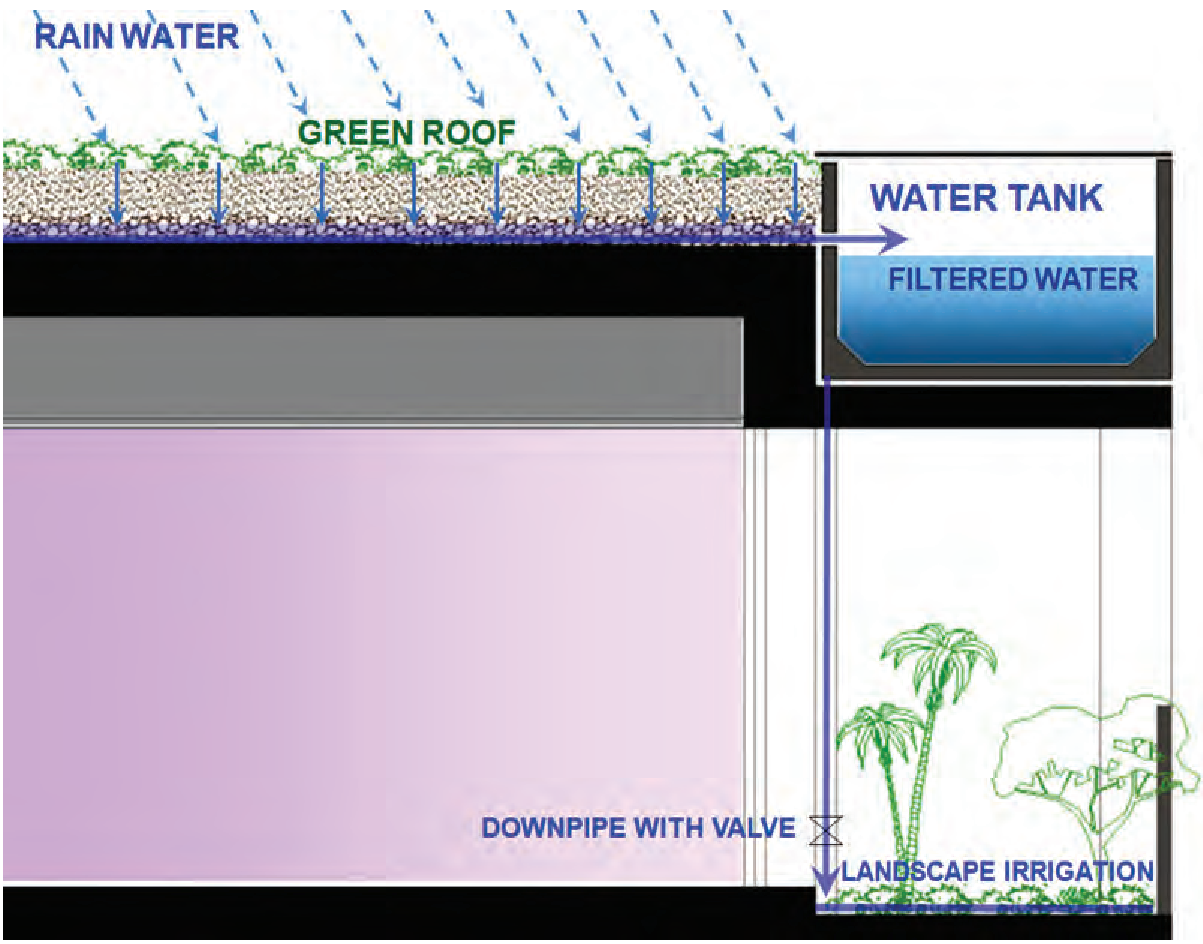
Four key water efficiency technologies for buildings are discussed in this section: metering and water consumption information, rainwater harvesting systems, grey water re-use systems, hydro-pneumatic water supply systems, and water-saving devices.

Metering and water consumption information is one of the key technologies to help manage water consumption. Conventionally, water consumption information is only provided in a form of monthly water bills without much detail in water consumption. Moreover, in many cases, users do not have access to such information, such as in commercial buildings or in multi-dwelling building complexes, where many units share one common water meter. Separate metering and provision of detailed water consumption information helps users to monitor the amount of water consumed and their consumption patterns. They help users to become more conscious in their daily water consumption and catalyse water saving behaviours.

Rainwater harvesting systems facilitate collecting good quality water from natural precipitation. The most popular method of harvesting rainwater is collection from roofs or other building surfaces. A simple system includes roof gutter and downspouts, which run into a storage tank. A detachable downspout is often used to exclude the first runoff during a rainstorm. The first runoff is usually contaminated with dust, leaves, insects or bird droppings (UNEP SBCI et al., 2007).

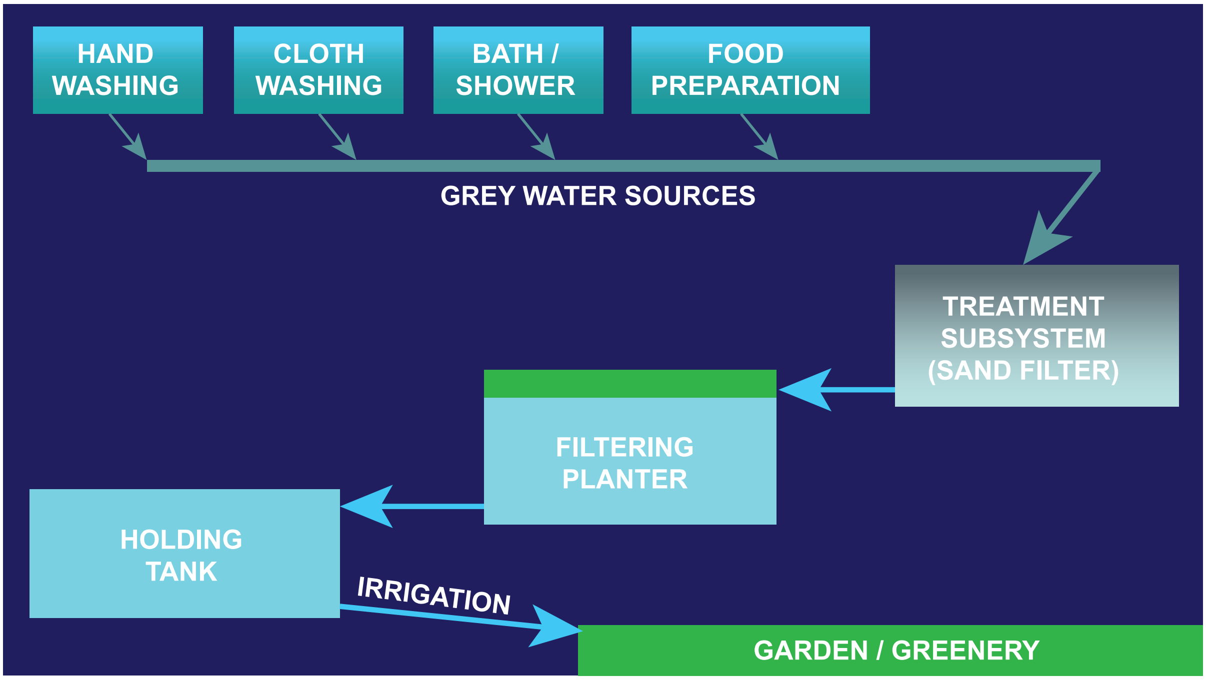
An advanced rainwater harvesting system includes a water treatment system (e.g., solar distillation), so that the harvested water can be treated to a potable level. An example of innovative rainwater harvesting application in multi-storey buildings places the rainwater storage immediately under the roof to take advantage of gravity for landscaping irrigation, toilet flushing, and other non-potable water usages.

Figure 4.9.1: Rainwater harvesting application in multi-storey buildings



Grey water reuse systems recycle and reuse grey water from shower/bath drain, basins and sinks for non-potable water uses, such as toilet flushing and irrigation, within a building. A grey water reuse system often consists of a piping network to channel grey water from its sources to a treatment system (e.g., sand filter and filtering planter), a holding tank, and distribution pipe to end use points, such as the irrigation system.

Figure 4.9.2: Flow diagram of a typical grey water re-use system

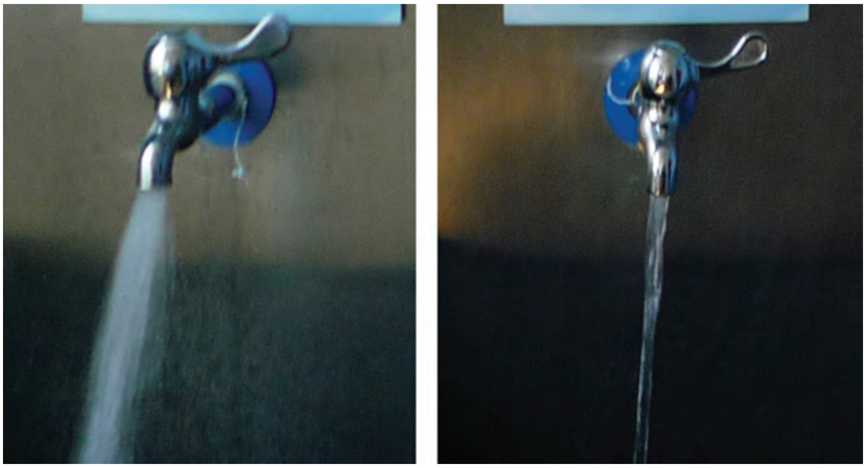


Hydro-pneumatic water supply systems introduce air pressure into water tanks as a key energy-saving component in water supply systems for building use. The compressed air in the tank serves three main functions;

1. Supplying water at a preset pressure range
2. Reducing pressure surges in the water supply systems
3. Using the pressure setting to monitor and control water pumps. Energy saving is achieved through reduced energy consumption from water pumps.

Water-saving devices: Four types of water saving device have been developed to save water consumption in buildings. First type of products applies aeration technology which mixes air to the water flow to reduce the amount of water released. This type of device acts as a water flow regulator and can be as simple as a thimble that can be fixed onto almost any domestic water tap, such as those at kitchen sinks and hand wash basins. Kitchen sink taps fixed with flow regulator can achieve a flow rate of less than 6 litres per minute without compromising the water pressure. Compared to the 15 litres per minute flow rate in typical kitchen water taps without regulators, the devices reduce water consumption by more than 60%. Aeration technology has also been applied to showerheads to achieve a flow rate of less than 5 litres per minute.

Figure 4.9.3: Water flow from taps with aeration regulator (left) and from tap without regulator (right)



The second type improves the design of toilets and urinals to reduce the amount of water released, while maximising the cleaning effect. For example, a water efficient urinal with a standard 300mm width only requires less than 0.5 litres of water per flush. For toilets, dual flushing cisterns have been developed to accommodate different flushing requirements. The recommended capacity is 4.5 litres or less for a full flush, and less than 3 litres for a half flush (BCA, 2007).

Figure 4.9.4: Toilet with dual flushing cistern.

The third type relates to water saving appliances, such as dishwashers and clothes washers. Technology development and new designs have resulted in significant water savings for these devices. For example, water saving dishwashers use about 14-38 litres of water, compared to the conventional ones that use 34-45 litres of water per load of dishes. The new design approach of clothes washers has moved away from top-loading models to front-end loading ones that use a tumbling action to wash clothes. Front-end loading washers use 30-50% less water, as well as 50-60% less energy to operate, compared to top-loading washers.

Figure 4.9.5: Water saving front-end washer (left) and conventional top-loading washer (right)

The fourth type relates to the design and application of automation technologies in landscape irrigation systems. For example, water saving drip irrigation systems use 30%-50% less water than sprinkler irrigation systems. Drip irrigation systems supply water directly to the roots of plants at a slow speed. As a result, water run-off and evaporation rates are kept to a minimum (BCA, 2007). Advanced water saving irrigation technologies also include automated controls that can be used with rain sensors. Irrigation is stopped when rain is detected. An automatic drip water irrigation system with rain sensors and timer controls in tropical regions can save 23% of the annual water consumption in a large building complex (BCA, 2007).

Figure 4.9.6: A drip irrigation system

Application requirements

Metering and water consumption information. In single dwelling units or small-scale single-owner buildings, water meters can be installed at the entrance point where the building's water supply pipe is connected to the municipal water supply pipe. A simple, small space should be provided to protect the meter from weather. The water meter, however, should be easily accessible for reading. It is usually located next to the entrance gates or front doors of buildings. In more complex buildings, which include several major water-consuming systems, i.e., hot water devices, landscaping irrigation and cooling towers, sub-meters can be installed for each of these systems. Data from all the sub-meters can be linked to the central building management system and provided to end users (where applicable) to optimise water usage and ease of leak detection.

Rainwater harvesting systems can be most easily applied in single dwelling units or townhouses, where homeowners can collect rainwater for their own consumption. In multi-storey buildings with multiple-owners, the harvested rainwater is best used for common areas that have non-potable water needs – i.e., landscape irrigation or cleaning of common areas. Rainwater collected from a roof should not be used for potable purposes without proper treatment. The size of a storage tank is based on the roof catchment area and local rainfall data, such as rainfall intensity, frequency and duration. Gutters and downpipes should be made of non-corroding materials, e.g., PVC, galvanised iron, etc., for durability and hygiene reasons. Rainwater harvesting systems require regular clean up of contaminants, dry leaves, etc., which could clog the system and pollute the collected water.

Grey water reuse systems. Conventionally, grey water and black water share the same piping network in a building. Black water is wastewater loaded with biological materials, discharged mainly from toilets. Grey water re-use systems require early attention at the building design stage, as the systems need spaces for additional piping networks, which is separate from the sewer, or the piping network for black water. In addition, treatment systems and holding tanks also require additional spaces. The stored grey water should be used as soon as possible. Preventive measures should be in place to disinfect the stored water to prevent cross contamination and the growing of bacteria and fungus. If the treated grey water is not disinfected, it is recommended to be reused only for irrigation via a subsurface system. Only when grey water is disinfected and treated to meet certain quality standards, can it be used for toilet flushing and surface irrigation (Government of Western Australia, 2010). Grey water re-use systems require regular maintenance to check for potential leaks, replace treatment medium, and to prevent mosquito breeding and bacteria growth.

Hydro-pneumatic water supply systems require space for the air-pressured water tank. It is usually placed on the roof of a building. The space should be large enough for the tank and for maintenance access. The roof and the supporting structure should be able to take in the additional load of the tank plus the designed maximum water capacity. Sensors are required to monitor the water level and pressure. The sensors send signals to control the operation of the compressor and water pump. It is best to link the whole system to the central building management system (if available) for centralised monitoring.

Figure 4.9.7: Rooftop space should be large enough for the water tank and maintenance access

Water-saving devices: can be easily applied in both new and existing buildings. Devices, such as aerators or flow regulators, can be simply added onto existing water taps. Dual flush low capacity flushing cisterns and water efficient urinals can be installed in new buildings or specified to replace existing conventional devices. There are no additional maintenance requirements compared to conventional devices.

Figure 4.9.8: Aerator fixed onto a tap as a simple way to achieve water efficiency

Water efficient irrigation systems. The irrigation frequency needs to be programmed to fit the weather and seasonal requirements. It is also recommended to identify opportunities for zone control, so that plants with different types of water needs are irrigated separately. Automatic controls can then be programmed to turn on/off the irrigation systems for different zones to meet various water needs. This arrangement will cut down unnecessary over watering.

Implementation status and market penetration

Water efficiency technologies and practices have, in general, been implemented in most regions of the world. Using simple forms of water metering for individual buildings is a mandatory practice in many urbanised areas, because municipal governments recognise that the practice can significantly influence user behaviours in conserving water. Two-thirds of Organisation for Economic Co-operation and Development (OECD) member countries have already installed water meters at more than 90% of single-family houses (Brandes et al., 2010). The complex application of sub-meters to major water-consuming systems in large-scale buildings requires additional investment and coordination efforts. Therefore, sub-meters are not as popularly implemented. However, their benefits have been recognised, and the implementation rate has been increasing, especially in water-scarce urban areas, such as Singapore.

Due to their tangible benefits and simplicity of installation and operation, rainwater harvesting systems are widely applied in rural setting and small towns, where a municipal water supply is limited or not available.

Grey water reuse is also a popular practice in its simplest form, in which grey water is manually stored for subsequent manual usage. Grey water reuse systems require additional space, an additional piping network and treatment equipment. Therefore, the technologies do not enjoy the same widespread implementation as rainwater harvesting systems do. The OECD, however, projects that more city governments will support and promote the implementation of grey water reuse in their cities, as they face “the increasing mismatch between the available water resources and rising demand, in both OECD and developing countries” (OECD, 2009).

Hydro-pneumatic water supply systems area proven technology to save electricity and lower pressure surges in water supply systems, without a large capital outlay. Therefore, the technology enjoys good market penetration, especially in high-rise buildings in urban areas, and buildings in areas with low-pressurised communal water supply, such as Calcutta, India and other cities in developing countries.

Low-cost water saving devices, such as water tap flow regulators and efficient shower heads, are widely implemented and have large market potential in both developed and developing countries. In the District of Saanich, British Columbia, Canada, the government initiated the Tap by Tap Energy and Water Saving Fixture Exchange programme to allow resident to exchange their shower, bath and kitchen faucet fixtures with a set of water saving ones. High-efficiency shower head, kitchen faucet aerator and bathroom faucet aerators are among the new set of water saving devices on offer. The objective is to help residents reduce their daily water consumption by 50% (District of Saanich, 2010). Dual flush low capacity flushing cisterns and water efficient urinals also have good potential to develop a major market segment for new buildings. Water efficient irrigation systems, however, have their market share limited to higher-end buildings.

Feasibility for implementation

Feasibility for implementation of water efficiency technologies and practices is usually contextually-based. In a rural setting where the communal water supply is limited or not available, rain water harvesting systems and grey water reuse systems are most suitable, and have already been established as a common practice in many such areas. In urbanised areas, where the communal water supply pressure is low or in high-rise buildings, a hydro-pneumatic water supply system will be most useful. Lastly, water-saving devices can be applied in most contexts.

In the case of rainwater harvesting systems and grey water reuse systems, institutional support is needed for effective large-scale implementation. The forms of institutional support may include and are not limited to:

1. Guidelines for design and installations of rainwater harvesting systems
2. Guidelines for preliminary water treatment and/or water purification for drinking (applicable for regions with scarce water resources and limited communal water supply)
3. Guidelines and regulations related to environmental health i.e., prevention of mosquito breeding in rainwater/grey water storage tanks/containers.

To support the implementation of hydro-pneumatic water supply systems, capacity building through training workshops will help establish a pool of local skilled technicians to design, install and maintain the systems. Incentive programs and demonstrations are helpful to promote large-scale deployment of these technologies.

In the case of water-saving devices, awareness raising programmes by local governments or NGOs will be the most useful first step. These activities help the general public understand the benefits and create buy-in. Furthermore, it is useful to introduce and implement labelling system for water saving devices. An example is the Water Efficiency Labelling Scheme by the Singapore Public Utilities Board. Labelling schemes such as this are useful to sustain public interest and promote the implementation of water-saving products and the related technologies, which help them become mainstream in the market.

Contributions to social, economic and environmental development

Water efficiency technologies contribute to environmental and resource protection through direct reduction of water and potable water consumption in buildings.

Energy consumption is also reduced by reducing the use of clean water and potable water in buildings. The saving is achieved not only through reduced on-site water pumping, but through reduced energy requirements to treat the water from the water treatment plant, transfer the water to end users, and treat discharged wastewater from buildings. Furthermore, hydro-pneumatic water supply systems are reported to save not only water but also up to 40% of the energy used by conventional water pumping systems (SBCI, 2010).

Rainwater harvesting systems also reduce the capacity stress to the storm water system. A large-scale deployment of the technology will help reduce surface storm water runoff and cut down peak discharge to the urban drainage systems. The resulted water and energy savings can be translated to tangible economic saving to both the local government (by reducing infrastructure-related expenses) and to homeowners who save on water bills. Rainwater harvesting systems, grey water reuse systems and the use of dual flush toilets directly engage end users to conserve water, resulting in building awareness and helping to instil positive environmental-friendly habits and practices in society at large.

Financial requirements

The financial requirements vary depending on the specific technologies, as well as the availability and suitability of a technology in a region. For example, in less dense village or town settings, the feasibility for implementing rainwater harvesting systems is high. The investment required for such systems is low, due to the availability of roof space and the already-in-place gutter and down pipe systems. The costs to the end-users are minimal, including water storage tanks, the optional detachable down pipes, as well as necessary maintenance. Rainwater harvesting systems in high-rise and high density urban environments, nevertheless, may cost more and are less cost effective. More sophisticated systems are required to cater for a small ratio of roof area over the number of users.

Some indicative costing examples are presented below. A rainwater harvesting system with an underground tank in Singapore costs about S$1,250/m^3, not including costs relating to excavation, backfilling, pipes connection, pump, filter, etc. (DLS, 2008). Alow-flow shower head costs about US$5 in the Caribbean region. Tap water flow regulators prices range from US$1.4–$4 for a domestic faucet aerator in the US, and about R95 in South Africa. A conventional water meter's price ranges from S$1,000 to S$3,000 each, and a digital meter's price ranges from S$3,000 to S$5,000 per unit in Singapore.

Case study

Umhlanga Sands Lifestyle Resort, Umhlanga, South Africa

The building is a 237-room resort on the beach front of Umhlanga. In its effort to reduce operational costs and conserve resources, the Resort invested R9,000 to install slow-flow shower heads and tap flow regulators. The flow was reduced from an average of 20 litres/minute to approximately 11 litres/minutes. This saves water consumption and the energy required to produce hot water, while the quality of the shower was not significantly compromised. The assessment showed that a saving of 41% of the electricity required for water heating is achieved in addition to reducing water consumption. The payback period was less than a month (Imagine Durban, Ethekwini Energy Office & Ethekwini Electricity Department, 2009).

4.10 Carbon-sink and low-carbon building materials and products

The technology

Materials and products used in building, such as steel and aluminum, are created by a production process of raw material extraction, raw material process, melting, manufacture to final products, and transportation to building site. Each of the steps consumes energy, which is also expressed in terms of carbon emissions. Total carbon emissions of all building materials and products and the construction involved to put them together is known as building's embodied carbon. Embodied carbon accounts for about 20% of the carbon emissions from the building sector (Lane, 2010).

Reducing embodied carbon is one of the simple and practical mitigation options for the building sector by utilising carbon sink and low carbon materials and products in buildings. Carbon sink building materials are mainly sourced from harvested wood products (HWPs). Wood is harvested from trees that capture carbon through the process of photosynthesis. Fifty per cent of the dry weight of wood is carbon, and the amount of carbon in 1m^3 of wood is similar to that in about 350 litres of gasoline (Labbe, 2010). It is important to ensure that the wood comes from sustainably managed plantations. Wood from illegal forest logging is not carbon-neutral and should not be used at all. Illegal logging permanently destroys vast natural carbon sinks and their associated biodiversity, which can not be easily restored. Using non-sustainable source harvest wood products is more environmentally detrimental than the benefits of using low-carbon materials in buildings.

Not all building materials can be carbon-sinks. In such cases, low carbon building materials should be used as much as possible. Low-carbon building materials can be sourced from materials with both low embodied energy and carbon in their production, assembly, and transportation processes. Due to the broad-based definition, low-carbon building materials are interpreted differently in different contexts. For example, metal products are considered to be high-embodied carbon materials because the extraction and refinement processes involved are carbon intensive. However, recycled metal products used in new buildings can be considered low-carbon.

Carbon sink building materials and products. The harvested wood building materials and products include flooring and cladding materials, window frames, doors, furniture, structural columns, beams and rafters. Bamboo products have recently received a lot of attention, due to its fast-growth, renewability and availability in both tropical and subtropical climates. Laminated bamboo has been found to be tougher than soft steel, and the surface is harder than that of red oak timber and fibreglass. Consequently, bamboos have been widely used in building structures, screen walls and as roofing components. Bamboo products have also found application in the high-end building market, for example, treated bamboo flooring.

Figure 4.10.1: Application of carbon-sink materials in buildings

Low carbon building materials and products have been the subject of research and development. This has resulted in many innovative building material products through the use of by-products and recycled products. Some examples of recently developed low-carbon materials and products in the market include:

1. Low-carbon bricks. These have been rolled out for mass production and implementation since 2009. The use of 40% fly ash (Ritch, 2009) helps to reduce embodied carbon found in conventional bricks. Fly ash is a fine glass powder that consists primarily of silica, iron and alumina. It is a by-product of coal combustion from electricity generation and is disposed of after being separated from the flue gas.

2. Green concrete. The raw materials to form conventional concrete can be substituted with by-products of industrial processes and recycled materials. For example, carbon intensive Portland cement can be substituted by fly ash and granulated blast-furnace slag. Aggregate or sand can be substituted by washed copper slag, and granite by recycled granite from demolished debris.

3. Green tiles. These are ceramic material made from over 55% recycled glass and other minerals. The products turn waste glass into tiles for use in building's internal and external flooring and cladding. The sparkling recycled glass components add an aesthetic quality to the products.

4. Recycled metals. The production process of metal products is highly carbon intensive. However, the life cycle performance of metal products can significantly reduce their production energy consumption, for example, by 95% for aluminium, 80% for lead, 75% for zinc and 70% for copper. This is because repeatedly recycled metals can still maintain their properties (Stewart et al., 2000). Other forms of utilising metal products without the full recycling process (which includes re-melting the old metal products and re-moulding them into new products) is to reuse existing metal structural components, such as steel columns and beams that still maintain their structural performance. Lastly, building-unrelated metal products, such as shipping containers, can also be adaptively reused in new building projects.

In addition to the examples above, there are many other innovative low carbon products available and many more are undergoing research and development.

Figure 4.10.2: Shipping containers can be adaptively re-used in new buildings

Application requirements

The vast opportunities for application of carbon-sinks and low-carbon materials and products can be identified in many building types and locations. On one hand, technical requirements for most of these materials are similar to any other ordinary materials used in buildings. For instance, harvested wood products, similar to the application of any conventional wood products in building, should be resistant to termite infestation and moisture damage. Technology-enhanced wood products, such as, involving lamination and chemical treatment, can reduce their vulnerability to termite infestation, and strengthen their water- and humidity-resistance.

Figure 4.10.3: Examples of timber construction detail

On the other hand, strict requirements do apply to the use of certain carbon-sink and low-carbon materials and products for safety and environmental health reasons.

The good intention of using carbon-sink and low-carbon materials may not achieve their optimal effect, if these materials are wasted during application. Materials are often wasted in order to achieve a certain perceived aesthetic effects. As a result, standardised modular materials are often trimmed off and cut at the construction site to meet the design intent, and the remaining materials become waste. Therefore, minimising waste by taking into account the standard sizes of building materials is a prerequisite in low-carbon building design practice.

Implementation status and market penetration

To mitigate climate change impacts from the building sector, low-carbon and especially carbon-sink materials and products have been considered as one of the most important mitigation opportunities. Many regional and national governments have established green building product labelling systems and carbon labelling systems, which further foster the implementation and market penetration of these materials and products. Examples of these systems are Taiwan's Green Building Material Label and Singapore's Green Building Products. These systems certify products, based on a number of environmental aspects, including low-carbon intensiveness, local materials, environmental health hazard, etc. Dedicated carbon labelling schemes for building materials and products is an emerging practice. However, it is currently grouped under carbon labelling systems, which cover all product categories – such as food and beverage products, cleaning products, etc. Examples of carbon labelling systems include Carbon Trust's Carbon Footprint, South Korea's Low Carbon Product Certificate and Thailand's Carbon Reduction Label.

Among carbon-sink products, bamboo has recently been recognised to have high potential. As the demand for harvested wood products increases, bamboo is used as a substitute for slower-growing wood species with high commercial potential. In 2007, bamboo represented 4-7% of the total tropical and subtropical timber trade (Lou et al., 2010).

Furthermore, innovative applications result in a wide range of bamboo products that are even recognised by many national building codes. For example, Colombia recognises the earthquake-resistant designs and construction methods involving bamboo in the nation's building code. Due to bamboo's widespread availability in developing countries, harvested bamboo products have strong market penetration potential and South-South transfer opportunities.

Feasibility for implementation

The feasibility for implementation of carbon-sink and low-carbon building materials and products is high. It is often dependent on architects' willingness to design and specify such products, and on building developers' acceptance. It also hinges on the local availability of the products. Four key success factors that facilitate such actions include:

1. **General awareness,** which can be built through public education campaigns, professional development programmes for building and construction professionals and developers, and supported by demonstration projects.
2. **Local availability of the materials and products.** An enabling mechanism is important to create the market and facilitate the development of the local building material industry. These materials and products should also be constantly upgraded to be technologically sound and cost effective.
3. **Institutional support** plays an important role in fostering the recognition, development, and implementation of carbon-sink and low-carbon building materials and products. One of the most effective tools is green labelling and carbon labelling schemes coupled with certification programs for building materials and products. These labelling schemes can be set up by government agencies or reputable NGOs.
4. **Capacity building** is a useful way of updating local professional and technical work forces about existing and new carbon-sink and low-carbon building materials and products.
5. **Research and development.** One of the most effective forms of collaboration are targeted research and development programs between universities, industry and government agencies. The objectives are to identify and develop new potential carbon-sink materials and products, and their innovative applications.

Contributions to social, economic and environmental development

Carbon-sink and low-carbon building materials and products offer a key mitigation option from the building sector while contributing to social and economic development, especially in developing countries.

Carbon sink and low carbon materials substitute conventional carbon intensive materials and reduce their demand. Buildings last for a long time, sustainable harvested wood products used in buildings offer along-term preservation and a sink for the carbon absorbed in the wood products. When stringent regulations are put in place for sources of harvested wood products, the demand for sustainably managed forests will increase,which in turn creates a stable source for legal HWPs. As a result, more carbon can be absorbed from the atmosphere and more green jobs can be created, in both the building and forestry sectors, contributing to the green economy.

Figure 4.10.4: Estimated carbon emission savings from substituting one cubic metre of timber for various building components [with reference to (Ruter, 2011)]

Substituted building components	Brick wall	Carpet	Aluminium window
Substituting building components (timber) (1 cubic metre equivalence)	Timber stud partition	Wooden flooring	Wooden window
Estimate emission saving (1 metric tonne CO_2 equivalence)	1.66	1.38	7.71

The widespread use of low-carbon building materials and products also promotes local environmental and socio-economic development. The use of locally available materials and products not only reduces the use of carbon intensive materials, but also reduces the embodied-carbon from long distance transportation. This also supports the development of local industries, which in turn provide jobs for local residents. Moreover, the increasing use of recyclable materials and industrial waste by-products reduces the need for waste treatment and disposal, reduce natural resource extractions and the energy required. This will also create an economy of scale to reduce the cost of recycled-content material production; increase the demand for the materials, which in turn help create a positive feedback loop; and make the use of low-carbon materials and products a mainstream practice.

Financial requirements

Because building materials and products are necessary to create a building, the financial requirements are less of an issue compared to that of other mitigation technologies. True carbon-sink and low-carbon materials and products should not incur an additional investment requirement. Their cost can potentially be even lower than carbon-intensive products, due to local availability that saves on transportation costs, and lower ingredient costs due to recycled or by-product materials that are substituted for virgin raw materials. Furthermore, many wood materials and products are conventionally used in buildings for a long time before the awareness of climate change. Therefore, the use of harvested wood products is not considered to incur additional investment cost.

Case study

Bamboo quake-resistant houses, Sichuan Province, China:

The project is part of the massive reconstruction effort of the earthquake-hit zone in Sichuan in 2008. Twenty houses were built with many building components made of bamboo, which are locally available in large quantities. In fact, one-third of China's bamboo species can be found in Sichuan, where the industrial output of bamboo is valued at more than 7 billion yuan (People's Daily Online, 2010).

The houses serve as a demonstration project but also to study the feasibility and application of prefabricated bamboo modular houses in terms of their ability to withstand strong earthquakes. The high fibre content of bamboo produces high tensile strength and good shock resistance, making bamboo a suitable for buildings in earthquake-prone areas. The houses were completed successfully in less than three months of design and construction. The performances of the house, such as durability, insulation, acoustics, and air quality were monitored and experiences were shared at a workshop (INBAR, 2010).

4.11 Greening and building integrated greenery systems

The technology

Greening the built environment is one of the most feasible and cost effective mitigation options for building sectors in rural and low density urban areas. Simple techniques, such as providing a garden and a pond, can be found in traditional houses in many countries. Taking a traditional house setting in Vietnam for example, plants in the garden provide vegetables and fruit, absorb carbon dioxide, offer shade and cool the ambient temperature. The pond collects rainwater run-off, supplies water for garden irrigation, and can be used to grow fish, and create a pleasant microclimate through evaporative cooling.

Building integrated greenery systems allows the provision of greenery beyond the conventional garden and courtyard, to the building itself (such as roof and façade) and even becoming part of a building component (such as a sky terrace). These technologies are relevant in high density urban settings, where land is scarce. They provide multiple benefits, such as lowering the ambient temperature, acting as additional insulation to roof and wall surfaces, thus reducing cooling load and saving energy. Plants also absorb carbon dioxide, help cleanse the air, and provide visual amenity.

Figure 4.11.1: Building integrated greenery systems

Green roofs are covered extensively with vegetation, such as grass or shrubs using an integrated support system. This system often includes substrate, filter, irrigation, water storage and drainage systems as well as water proofing of a roof surface/structure. In-situ installation is a conventional green roof application. It involves assembling the green roof layer by layer directly on the roof. The size and shape of the layers are configured to suit the roof design. Green roofs are designed to be lightweight, and typically cannot support heavy activities, just maintenance.

Roof gardens, balcony gardens and sky terraces are gardens with plants located on rooftops, balconies and terraces of buildings with accessibility for outdoor activities. Plants on these gardens can be more diverse and often include trees in addition to grass and shrubs. Depending on the type of plants it supports, soil depth typically ranges from 0.2m to over 1m (NParks, 2002). Integrated irrigation, drainage and waterproofing of the roof surface are common components of a rooftop garden.

Green façades/wall sallow plants to grow on building façades/wall surfaces through various means i.e., creepers with self clinging roots on wall surfaces, twining plants on mesh or cable support, and carrier panels with pre-grown plants fixed vertically on walls (NParks, 2009). Lightweight supporting structures can be made of polypropylene-based or synthetic fabric materials, while lightweight growing mediums consist mainly of volcanic stones and pumice.

Figure 4.11.2: Common green façade/wall types

Creepers on wall surfaces | Mesh/cable support | Carrier panels

Although building integrated greenery systems are not a new concept, their application has been picked up in recent years offering opportunities for further research and development, innovation and improvement.

An important ongoing research and development area is plant selection for various climatic regions and greenery systems. For green roof and green façades/wall applications, the selected vegetation must be able to thrive under intense sunlight and be drought-resistant. Selecting plants with shallow roots is a criterion to meet the light-weight and low maintenance nature of green roof systems. Other criteria in plant selection include:

1. Plants with thicker and denser coverage of leaves for better shading effect and better thermal performance
2. Use of native plants to nurture local biodiversity.

In the technological aspect, the performance of building integrated greenery systems has been improved, thanks to the development of new substrate system, built-in automatic irrigation systems with rain sensors, and built-in drainage systems. Such technologies help to make the greenery systems more lightweight, more water efficient, less maintenance intensive, and to eliminate potential water leakage problems.

The application of green roofs and green façades/walls is also shifting from in-situ application (i.e., assembling the green roof layer by layer directly on the roof) to modular based. Such application provides shorter installation time, minimum risk of damaging building materials, flexibility in design (in terms of mixing and matching various type of plants to create interesting design patterns), and ease of maintenance and replacement.

In green roofs, modules are small trays with sizes ranging from 0.25 to 2m^2. Each tray is equipped with drainage, drip irrigation (optional), filter layer, substrate, media layer and grass/shrubs. In green façades/

walls, modulisation is applicable for carrier system types. Each carrier panel is a module with a depth ranging from 100mm to 250mm. The modules can be lined up on a metal frame, which is fixed onto façade/wall surface. Irrigation and drainage pipes are interconnected between the modules and hidden within or behind the frame.

Figure 4.11.3: Green façade modular system embedded with irrigation and self drainage technologies

Application requirements

Building integrated greenery systems are most useful and feasible in cities and densely populated areas. To counterbalance the densely built-up environment, such greenery areas create alternative spaces for gardens, leisure activities, open spaces and a pleasant urban living environment. Building integrated greenery systems are most appreciated in tropical regions and in temperate regions in summer months. Under such climatic conditions, plants thrive and thus optimise their environmental benefits. However, these systems may not be suitable for application in hot or arid climatic regions, where most plants may not survive the heat.

The various systems described above have the same objective of integrating greenery into buildings, and thus share several issues that require technical attention and solutions. These issues include:

1. Building structure must be able to support additional loads on the roof and/or on walls, depending on the greenery systems installed.
2. Roof, sky terrace/balcony floor surface and façade areas must have proper waterproofing and measures to prevent root penetration and structural damage.
3. The risk of plants or tree branches falling from the buildings must be prevented. Measures include additional securing of trees/plants and regular maintenance procedures.
4. Irrigation, water storage and drainage systems need to be designed, installed and maintained appropriately to match local climatic conditions.

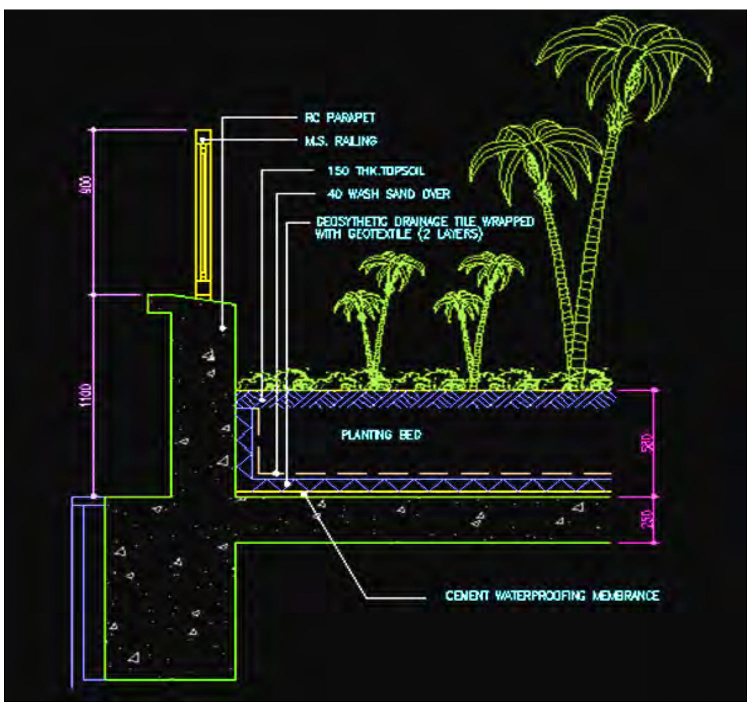
5. Substrate and media for plants to grow on should be lightweight and designed to allow secure root penetration by plants.

Although there are common application requirements, different building integrated greenery systems have distinct application requirements:

Green roofs are most suitable for existing buildings in urban areas. This is because their lightweight system and public inaccessibility do not add significant additional dead-loads on existing roofs, and do not pose any security concerns. To be suitable for a green roof, an existing building roof needs to be relatively flat, with access for installation and periodic maintenance.

Roof gardens, balcony gardens and sky terraces require early design decisions for spatial and structural provisions to allow for additional dead-loads and accessibility for leisure activities. Therefore, these systems are mostly installed in new buildings. Design of sky terraces should also allow for an appropriate height-to-depth ratio for sunlight penetration. The appropriate ratio varies from region to region, depending on the latitude and orientation of the sky terrace. In tropical regions, a ratio of 1:1 is considered to be sufficient regardless of orientation. However, in Eastern and north-eastern Europe, it is unadvisable to place sky terraces or balcony gardens on the northern side of a building, as plants may not grow well with limited sunlight accessibility. Likewise, in far southern regions of South America and Africa, sky terraces and balcony gardens should be placed on the northern side of the building for sunlight accessibility.

Figure 4.11.4: Sectional detail of roof garden



Green façade/walls can be implemented on both new and existing buildings. They can be very effective in terms of reducing heat gain, if installed on a building's west facing façade. Furthermore, they can be strategically placed to hide undesirable elements/components of buildings, such as mechanical and electrical plant rooms. For carrier systems, the plants are pre-grown on panels with a lead time of about 3 to 8 months depending on the plant type. When installed onsite, a carrier system can provide an instant lush effect. However, for support systems, it should be noted that climber plants can take up to 3 to 12 months to grow on site (Chiang, 2009).

Figure 4.11.5: Support system green façade to cover a mechanical plant room

Implementation status and market penetration

Green roofs: Due to their limited benefit – i.e., inaccessibility for leisure activities and maintenance requirements, green roofs have not been widely implemented. Their application is mainly for retrofitting existing buildings that have flat concrete roofs. This building configuration constitutes only a small segment of the existing building stock. Therefore, the market potential is limited.

Roof gardens, sky terraces and balcony gardens. Because the additional cost incurred to make provision for additional structural supports and maintenance requirements,these building integrated greenery systems are mainly implemented in newly constructed high-end buildings. However, the potential market for roof gardens is high in the tropical bell regions of China and India, where both population growth and urbanisation rates are high. In these countries' high density cities, with high land cost and land scarcity, roof gardens, sky terraces and balcony gardens provide alternative spaces for leisure outdoor activities and improve biodiversity.

Figure 4.11.6: Roof garden creates a view, improves connectivity, and increases greenery and open space at the Institute of Technical Education College East, Singapore.

Green façades/walls: Due to the difficult and frequent maintenance requirements, green façades/walls are not widely implemented and have limited market penetration. They are mainly implemented for their aesthetic benefit in institutional buildings and in retail and entertainment complexes. The environmental benefits are often considered as a secondary objective. However, given the large area of building surfaces in an urban setting, green façades/walls have enormous potential to be implemented at a much larger scale to provide a positive environmental change in densely populated cities (GRHC, 2008).

Figure 4.11.7: Greenery as integral component of building design at Singapore Management University, Singapore

Feasibility for implementation

Building integrated greenery systems are more feasible for implementation in urban settings, especially in densely populated cities where land available for gardens and greenery is scarce. High land prices make it less feasible for developers and building owners to set aside sufficient land area for conventional on-grade gardens, open spaces and public spaces. It makes more economic sense to provide alternative green spaces integrated in buildings to provide leisure and, to a certain extent, communal activities. The cost to install and maintain building integrated greenery systems are easily offset by the high land prices and increase in property value.

Without government intervention,implementation of building integrated greenery systems will only be implemented in an ad-hoc manner by a small group of socially- and environment-friendly conscious building developers. Scientific based policy tools can facilitate the widespread application of building integrated greenery systems. For example, in Singapore, the concept of the Green Plot Ratio is developed to be a tool to quantify the environmental benefits of integrating greenery into buildings three dimensionally. Instead of measuring the greenery provision of a building site in terms of a two-dimensional area, e.g., percentage of green coverage in China, Green Plot Ratio measures the total leaf area index over a building site using a volumetric approach, taking into consideration green walls, green roofs, sky gardens, etc. (Ong et al., 2003).The Green Plot Ratio has been adopted in building regulation, i.e., Singapore's Code for Environmental Sustainability of Buildings.

Government incentives are also necessary for the large-scale implementation of building integrated greenery systems. In several countries, governments incentivise developers and building owners through cost sharing methods. In Singapore for example, the National Parks Board administers the Green Roof Incentive Scheme, in which the government shares up to half of the cost of green roof installation capped at S$75 per square metre for buildings in the city centre areas (NParks, 2010).

Incentivising policies for one greenery system can also be a catalyst for the widespread implementation of other greenery systems. In Tokyo, for example, the city government targeted rooftop gardens, setting up the programme to support the creation of at least 12 km^2 of rooftop gardens by 2011, many types of building integrated greenery systems have benefited from the programme. Green façades have also attracted more interest and have been marketed to architects, contractors and developers (Dunnett et al., 2008).

In regions where building sector professionals and related trades are not familiar with building integrated greenery systems, capacity building is needed prior to large-scale implementation of the technologies. Capacity building should be in the following areas:

1. Planning, designing skills and plant selection, so that building integrated greenery systems can contribute positively to the local biodiversity and eco-system
2. Installation techniques (for trade technicians), including water proofing and irrigation systems
3. Maintenance procedures (building's owners and facility management personnel)
4. Manufacturing and supplying light-weight components for green roofs and green façades/walls modules.

Contribution to social, economic and environmental development

Integrating greenery systems into buildings brings many benefits for the environmental, social and economic development of cities and dense urbanised areas.

The environmental benefits include:

1. Reducing heat gains for buildings in hot climatic regions. Research findings show that green roofs can reduce roof surface temperatures by 30^{0}C (Wong et al., 2003). Similarly, green façades can reduce the temperature immediately outside the façade by 5.5^{0}C, creating a 50-70% reduction in energy demand for air-conditioning (Peck et al., 1999).
2. Reducing the heat island effect in urbanised area by shading heat-absorbing building surfaces, such as concrete, masonry, metals, etc. Green roofs can reduce immediate ambient air temperature by about 4^{0}C in tropical regions (Wong et al., 2003).
3. Absorbing airborne particles and improving ambient air quality in urban settings. Green façades/ walls located near busy roads can break down and absorb volatile organic compounds and unburnt hydrocarbons from vehicle exhaust (Chiang et al., 2009). Creepers also have a well-developed capability to trap and filter dust in their tissues (Johnston et al., 1993).
4. Nurturing and enhancing urban biodiversity, especially when selecting indigenous vegetation species and coordinating building integrated greenery systems in a larger urban greenery network.
5. Reducing rainwater run-off during downpours through rainwater retention by greenery and water storage in building integrated greenery systems.
6. Absorbing carbon dioxide for photosynthesis and, as such, acting as carbon sinks.

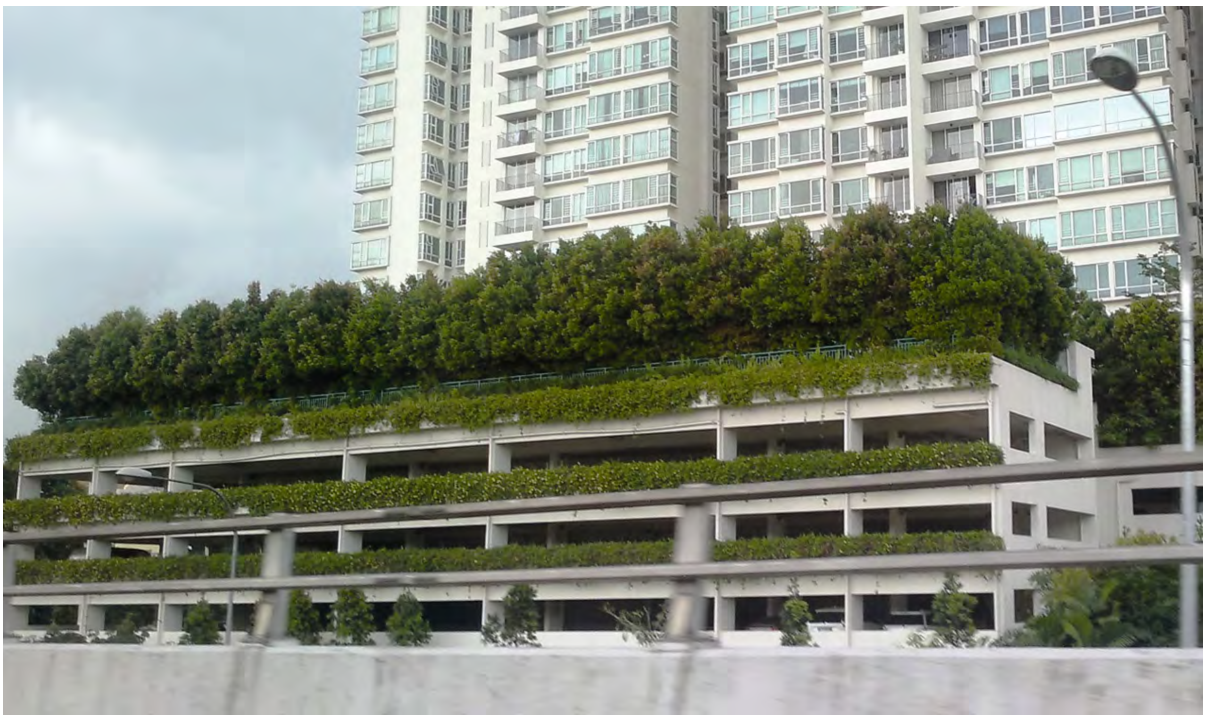
Figure 4.11.8: An effort to promote urban biodiversity by providing planting strips, connecting greenery on the ground to rooftop garden in the Solaris, One North, Singapore

The benefits related to social development include:

1. Creating biophilic value to building occupants and city dwellers, and encouraging them to lead environment-friendly lifestyles.

2. Providing alternative public places for leisure activities and fostering community ties through the opportunities of interaction in a high-rise urban setting.

Figure 4.11.9: Green wall and roof greenery as environmental buffer for a residential development fronting a busy road



The economic benefits of building integrated greenery systems include:

1. Reducing building cooling load, leading to lower energy consumption and thus cost savings to building owners/tenants.

2. Enhancing the marketability for buildings and increasing property value, thanks to their increased aesthetic appeal and biophilic value (Chiang et al., 2009).

3. Reducing the diurnal temperature fluctuation of the building roofs and façades, leading to a reduction in materials' contraction and expansion, thereby prolonging the lifespan of building roofs and façades. Research findings from the tropical region show that the change in temperature from day to night on a typical concrete wall is approximately 10^0C, whereas the temperature change on a similar concrete wall equipped with a carrier greenery system is as low as 1^0C (Wong et al., 2009).

4. Nurturing the prosperity of new supply chains and new job creation to support a green economy.

Figure 4.11.10: A green wall helps to reduce the diurnal temperature fluctuation of the building façade.

Financial requirements

Financial requirements for building integrated greenery systems include the investment cost of the products and their installation, and ongoing maintenance costs. These costs vary from system to system and from region to region. The following are indicative costs and considerations.

Green roofs. The investment cost for a lightweight, modular green roof system in Singapore ranges from S$150 to S$400 per square metre (DLS, 2009). In China, the indicative initial investment cost for green roofs ranges from 200-1,000 Yuan per square metre (China Real Estate News, 2010).

Rooftop gardens, sky terraces and balcony gardens. The investment costs vary depending on how elaborate the gardens are. These costs are similar to the cost of building a conventional on-grade garden plus additional costs for the stronger building structure and waterproofing measures and additional drainage system. Maintenance costs are also higher compared to that of an on-grade garden.

Green façades/walls. The investment costs for green façades/walls vary depending on the system. The cost of the support system is lower than that of the carrier system, which is in the range of S$300-S$2,000 per square metre. This cost range does not include the structural steel frames and drip irrigation. It is suggested that a budget be allowed for replanting in 1-2 years time (DLS, 2009).

Case study

Rooftop gardens on the top of integrated multi-storey car-parks have become a popular feature in Singapore high-density public housing since 2000. Such provisions are a response to land scarcity in the island city. They maximise the use of land for car parking (addressing the environmental issue of conventional surface parking) and at the same time provide lush green rooftop garden areas for the residents. Figure 4.11.11 shows a typical roof garden in Punggol public housing. The rooftop of the multi-storey carpark is covered with intensive greenery and is accessible to the residents of the surrounding housing blocks. Research findings show that vegetation can prevent the temperature of the roof from increasing significantly under strong sunlight. On a roof surface without plants, the surface temperature can increase to a high of 58^{0}C, whereas a rooftop garden area typically has a surface temperature below 31^{0}C. The ambient air temperature on the rooftop garden can also be 4^{0}C lower compared to a roof without plants (Wong, 2003). As such, rooftop gardens not only provide a communal greenery area for residents' leisure activities, but they also help cool down the ambient temperature and reduce the urban heat island effect.

Figure 4.11.11: Rooftop garden of a public housing precinct in Punggol, Singapore

4.12 Solar technologies

The technology

Solar technologies facilitate the extraction of a renewable energy source by harnessing power from the sun. There are two technological principles that can be used to achieve this:

1. Collecting thermal energy from the sun (known as solar thermal)
2. Converting light into electricity (through the photovoltaic process).

Both solar thermal and photovoltaic (PV) can be integrated into buildings. Applications for PV include building integrated photovoltaic (BIPV), solar home systems (non-grid connected) and solar charging stations. Solar home systems and solar charging stations are most suitable for application in rural and remote areas where grid power is not readily available. Most BIPV applications are grid connected enabling surplus energy produced to be exported to the grid.

Solar thermal water heater. In its most basic form, the system consists of a collector and a water storage tank. The collector is a flat plate comprising a black coloured metal sheet with metal tubes attached to it. The metal sheet is backed by a thermal insulation layer, and covered on top with a glass panel to reduce convective heat loss and provide protection from the weather. The collector tube is connected to a water tank which is located on top of the collector. The collector absorbs solar heat radiation, which is transmitted to the water circulated in the metal tube. The heated water then rises and is stored at the water tank through natural convection. Cool water automatically fills the space in the metal tube.

Recently, the use of solar thermal energy has expanded to include dual use systems, combining both water heating and space heating (combi-systems). These systems reduce energy consumption for space heating during the winter season for buildings located in temperate regions. One disadvantage is that the systems have to discharge surplus heat during the hot summer season. This issue has been overcome by combining solar cooling and combi-systems, which maximises the usage of solar thermal technologies year-round (Troi et al., 2008). Solar cooling makes good sense for application in hot climatic regions. During a typical day, the peak demand for space cooling matches the peak of solar radiation. As such, the large scale implementation of solar cooling technology will contribute to reduced electricity peak loads.

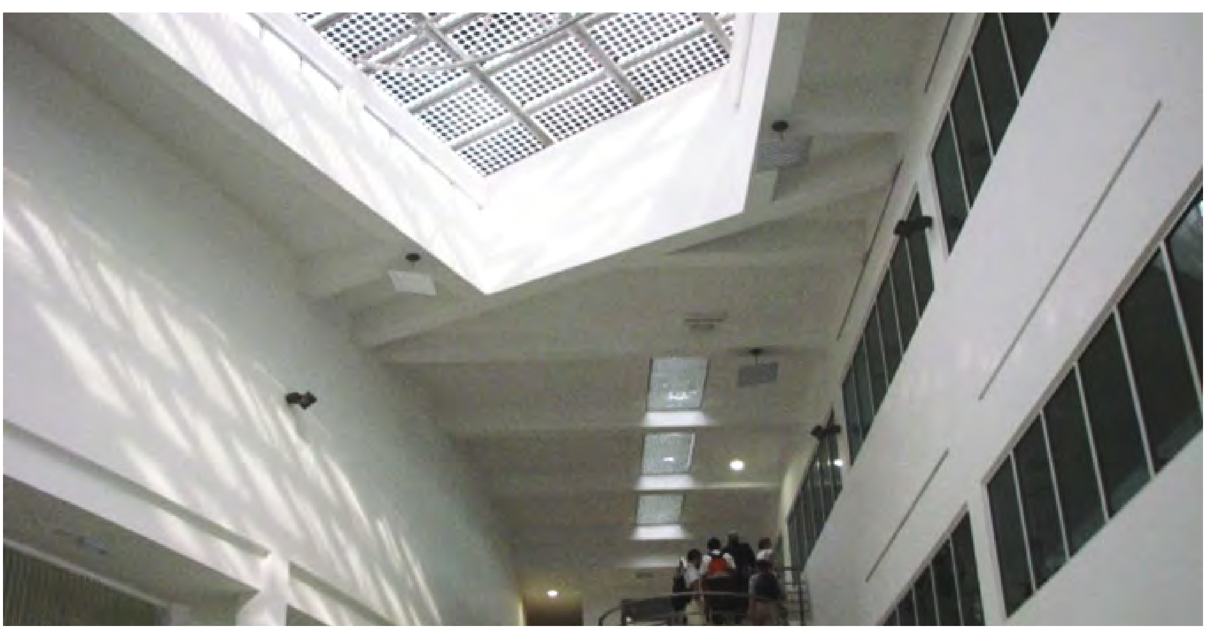
Figure 4.12.1: Solar thermal water heater (left), photovoltaic panels (right)

BIPV. A BIPV system consists of PV panels and a DC-AC inverter. A PV panel includes a series of connected cells made of semiconductor materials. When PV modules are exposed to sunlight, they generate direct current (DC) electricity, which is most often converted to alternating current (AC) electricity – a common form of electricity that can be used in most current appliances and lighting systems. The AC electricity can then be fed into one of the building's AC distribution boards, or connected to the main electricity grid. PV panels, which are integrated into the roof, façade, skylight or sun-shading devices, are referred to as building integrated photovoltaic technologies (BIPV). With BIPV, PV modules are usually used as a substitute for other building components, e.g., sun-shading devices, thereby offsetting some of the cost.

Figure 4.12.2: PV panels as integral part of building design

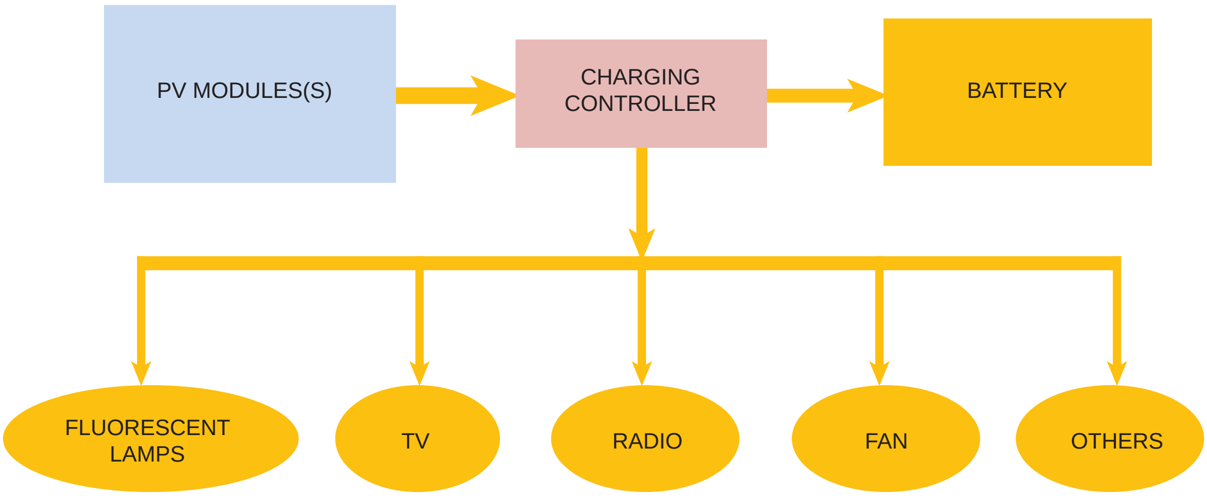
Although considered to be a proven technology, PVs are still under research and development, especially to increase the efficiency of energy production and to reduce manufacturing costs. The common PV technologies can be broadly categorised into two groups – crystalline silicon and thin film. Crystalline silicon technologies account for the majority of PV cell production, whereas thin film is newer, less efficient, but growing in popularity (EMA & BCA, 2009).

Figure 4.12.3: BIPV: PV modules sandwiched between glass panels of skylight over an atrium



Solar home system: is developed based on photovoltaic (PV) technologies and integrated with DC-electricity-based appliances. It is the most suitable technology used in remote and rural areas, which are not served by the electricity grid (Grimshaw et al., 2010). The technology has been implemented in villages and remote settlements in Africa and Asia. A typical system consists of a 10 to 50 Watt Peak PV module, charging controller, storage battery, and various end-use equipment that operate with DC electricity (e.g., fluorescent lamps, radio, television, fan, etc.).

Figure 4.12.4: Diagram of a typical solar home system



Solar charging station: is another application for PV technologies. A typical solar charging station includes PV module(s) to generate electricity, a charging controller to normalise the voltage, and a battery bank to store the DC electricity. The electricity from the battery bank can then be used to charge batteries for various uses, such as lights, mobile phones, and other DC-electricity-based appliances.

Application requirements

Solar technologies perform better in regions and seasons with the highest sun intensity and long sunlight hours. Building rooftops are the most logical location for the installation of solar thermal and PV technologies. Prior to the installation of a large number of solar panels, it is important to ensure a roof's structure is strong enough to hold their weight. Accessibility for maintenance should also be planned for. It is recommended that preventive inspections and maintenance are carried out every 6 to 12 months. Inspection includes checking for signs of damage, dirt build-up or shade encroachment(BCA & EMA, 2009).

Solar thermal water heater. These systems are most often used in urbanised areas, which have access to a stable water supply. Water supply stability is required for automatic operation of solar thermal water heaters. In these systems, pressure from the water supply system must be high enough to allow for automatic refilling of water into the heating pipes. The water supply pressure can be provided by the city main water supply system, or locally produced by pumping water up to a level higher than the installed solar thermal water heater. The second option requires electricity for pumping, and this will reduce the cost-effectiveness and energy-efficiency of the system. However, solar thermal water heaters do not require extensive maintenance, once installed.

Figure 4.12.5: Solar thermal system installed on building's rooftop

BIPV, solar home system and solar charging station. The core technology of these three systems is PV. The crucial condition of PV applications is that the locations must be exposed directly to sunlight and are not shaded. The reason is that PV modules, crystalline silicon technologies in particular, are very sensitive to shading. Taking a module consisting of 36 PV cells as an example, if one cell is shaded, the cell, instead of producing, can consume the energy produced by other cells, due to their string connectivity. Electricity production of the whole module, in this case, can be reduced by up to 50%. Therefore, shading must be avoided. Preventive measures include periodic maintenance to clean the surface of the modules (e.g., accumulated dust and/or bird droppings).

In order to maximise the yield, PV panels should be mounted so that they face the sun directly. In temperate regions, such as Eastern Europe, PV panels should be mounted with a suitable sloping angle toward the South, whereas, in the tropical regions, especially in the regions near the equator, flat-mounted PV panels provide the best yield. However, the flat-mounted PV panels will result in poorer self-cleaning performance and tend to accumulate dust, which in times causes shading to the cells and diminishes the system's outputs. A slight inclining angle of 3 to 5 degrees, to allow for rainwater properly drained off and promote self-cleaning, is useful and acceptable. Regular maintenance is required.

Implementation status and market penetration

Solar energy is considered one of the most promising renewable energy technologies. The International Energy Agency estimates that the contribution of solar energy to the global electricity demand will increase from about 0.02% in 2007 to approximately 1% by 2030 (IEA, 2009). The IPCC reports that in 2003, there were more than 132 million square metres of solar collector surface for space and water heating worldwide (Levine et al., 2007). China accounts for closed to 51.4 million square metres, followed by 12.7 million square metres in Japan, and 9.5 million square metres in Turkey (Weiss et al., 2005) Recognising the high potential of solar energy, governments around the world are paying attention to and preparing for its large-scale implementation. This creates a strong market penetration for solar technologies. For example, in China the annual growth rate of the installed area of solar panels has been steady at around 27% from 2000 to 2005. (Abbaspour et al., 2005). The Chinese solar market initially targeted installations in villages and small towns, but has recently gained a strong foothold in urbanised areas.

The present and potential markets for large scale implementation of solar technologies are in rural settings and areas not served by the power grid. In these areas, the cost to install solar power can usually be justified when compared to the high infrastructure cost to extend the power grid or to build a power plant.

Solar thermal water heater. Solar thermal water heaters have enjoyed good market penetration, compared to PV technologies, which are considered more costly. In Rizhao, China, for example, 99% of homes are reported to use solar water heaters (Grimshaw et al., 2010).

The supply of hot water in non-temperate regions can be regarded as a less crucial issue and can even as luxurious, such as in the case of Africa. It is observed that the bulk of solar thermal water heaters in use there are bought by high-income households and large commercial establishments such as hotels (Karekezi, 2002). The use of hot water, and thus the need and potential market for solar thermal water heaters, are more pressing in colder climate regions, such as villages or towns in north-eastern European countries, mountainous areas of the Andes and the Himalayas (SEPCO, 2010).

PV technologies: PV-related technologies, such as BIPV, solar home systems, and solar charging stations, are more capital intensive to invest in and require more stringent installation requirements due to their sensitivity to being shaded, when compared to solar thermal. Therefore, PV technologies at the present have smaller market penetration. However, research findings show that almost all developing countries have enormous solar power potential. For example, many regions of Africa have 325 days of strong sunlight each year. This can lead to an average of more than 6kWh energy harvested per square metre a day (Grimshaw et al., 2010).

Future markets for PV technologies include urban settings, in particular when smart grid systems and policies that provide incentives for a feed-in tariff from renewable energy become mainstream.

Feasibility for implementation

Experience suggests that the availability of strong institutional supports, especially incentivising policies and supportive financial mechanisms, are the key first steps to make solar technologies mainstream. These include but are not limited to:

1. Reducing/removing subsidies for fossil-fuel-based electricity supply.
2. Reducing/removing import tariffs on solar technologies' components.
3. Cleary identifying power grid expansion plans (for rural and remote areas) and communicating these plans clearly to the public. This is necessary for calculating payback periods used in decision making processes to invest and implement off-grid solar technologies, such as solar home systems and solar charging stations.
4. Setting up smart grids and incentivising feed-in tariffs (in urbanised areas) as a platform to promote on-grid application of PV technologies, such as BIPV.

In the regions, where the solar technologies have not been or only ad hoc implemented, research and development is an important first step to determine the feasibility of implementation. The areas to be given priority include:

1. Collecting local solar radiation, intensity and sunlight hours available during various seasons.

2. Researching the most suitable, efficient, and cost effective solar technologies and products for large-scale deployment.

3. Establishing viable business models and financial mechanisms for a reasonable return on investment.

These activities can be done through establishing a research institute, which can be in the form of collaboration with local government and universities.

Capacity building should be in the area of technical knowledge, design techniques for building professionals, installation skills for technicians, and routine inspection and maintenance for home/property owners and facility management personnel.

Contribution to social, economic and environmental development

Solar technologies hold a prominent and promising role in climate change mitigation by replacing fossil-fuel-based electricity production. Taking solar home systems as an example, a typical system of 10 to 50 Wp (Watt peak) will directly displace about 0.15 to 0.3 tonnes of CO_2 annually through fossil fuel substitution (Kaufman, 1990).

Regarding the social development aspect, solar technologies improve the quality of life and contribute to a healthy environment. Solar thermal heaters provide hot water to millions of people in the mountainous Himalayas and in China. The use of solar home systems reduces the need to store and burn kerosene for lighting, improving health and reducing fire hazards for villagers in Africa and rural Asia. Solar home systems also make information and entertainment accessible to rural areas with the use of radio and television.

In terms of economic development, solar technologies bring direct benefits to households, and to regional/national economies. The IPCC's Fourth Assessment Report estimates that BIPV could generate enough energy to meet 15% of total national electricity demand in Japan, and close to 60% in the US (Levine et al., 2007). At the household level, the application of BIPV reduces monthly electricity expenses and provides the opportunity for building owners to sell surplus electricity to the grid. The implementation of solar charging stations provides opportunities for new businesses that are environment-friendly. Large-scale implementation of solar technologies, through capacity building, provides new skills and sources of income for local work forces. Studies have shown that investment in solar technologies would create additional jobs even in oil-rich Middle East countries such as Iran (Abbaspour et al., 2005).

Financial requirements

Financial requirements for solar technologies include the investment costs of the products and installation, and maintenance costs. In general, it is expected that the investment cost of solar technologies will decline as a result of improved technology and increased mass production, made possible through higher market demand. The cost components also vary depending on the technologies and whether the products are produced locally or imported. The following includes some indicative figures and considerations:

Solar thermal water heater. In the Caribbean region, a solar thermal water heater for a typical household costs between US$1,500 to over US$2,000. This initial investment cost has a payback period of 2 to 2.5

years in most Caribbean islands, (Escalante, 2007). In India, the investment cost of a solar thermal water heater is about INR15,000 to INR 45,000.

BIPV. The initial investment cost of a BIPV system is high, whereas the operational costs are negligible during the warranty period. As a rule of thumb, after the warranty period, the annual maintenance cost may amount to 0.5 to 1% of the investment cost. It is also observed that historically the cost of PV has been falling by about 4% yearly. If the same trend continues, it will take about ten more years for PV to be competitive (EMA & BCA, 2009). In Singapore, the investment cost for PV ranges from S$8 to S$12 per Wp with a normal warranty period of 25-30 years (DLS, 2009).

Solar home systems. The investment cost of a full solar system in Africa typically ranges from US$250 to US$630 (Davies, 2010).It has been reported that a solar home system in Africa has a payback period of less than two years in combination with the right financial mechanisms (Grimshaw et al., 2010).

Case study

The Barefoot College in Tilonia, India is well known for at least two aspects related to solar technologies. Firstly, the campus is a fully solar-electrified campus. It was designed and built by a team of rural Tilonia residents for their own rural community. The campus has 45 kW of PV modules, supported by 5 battery banks. The PV systems produce electricity for 500 lights, fans, a photocopy machine and over 30 computers and printers (Barefoot College's website). Secondly, Barefoot College offers unique training programme to transform rural men and women to become solar specialists and technicians.

The training programme has been extended beyond the India border to Afghanistan, and as far as Jordan and other countries in Africa. The programme admits only students with no formal education who are living in rural and remote areas. The students normally spend about six months at Barefoot College to learn about solar technologies, before returning to their home village to lead activities that foster the implementation of solar technologies to their own communities. Financial assistance for the students is often granted by government-to-government supports/programmes, such as the India Technical Economic Cooperation Programme (Luck, 2010).

4.13 Building integrated wind turbines

The technology

Wind energy technologies can be classified into two categories – macro wind turbines that are installed for large-scale energy generation such as wind farms, and micro wind turbines used for local electricity production. Micro wind turbines are suitable for application at the building scale and are called 'building integrated wind turbines'. The main components of a wind turbine include blades, rotor, gearbox and generator. Small wind turbines were originally designed with a horizontal axis, also known as HAWTs. To reduce the need for a high tower, and for aesthetic reasons, vertical axis wind turbines (VAWTs) become increasingly popular for integrated building applications. Furthermore, VAWTs are also quieter (resulting in less noise nuisance) than HAWTs during operation.

Figure 4.13.1: Horizontal axis wind turbine (HAWT)

Wind turbines can be grid-connected or off-grid. Off-grid systems require battery storage to store surplus electricity, thereby providing a more stable electricity supply. Their application is most suitable for rural and remote areas, such as remote villages and small isolated islands, where grid power is not available. Conventionally, grid-connected systems require power converters to convert the generated DC electricity to AC electricity to be compatible with power grid and AC-electricity-based appliances. As technologies improve, modern wind turbines can also directly generate AC power.

Recent developments in building integrated wind turbine technologies involve improving reliability, improving efficiency at low wind speeds and lowering capital cost. Wind turbine blades are now designed with lightweight materials and aerodynamic principles, so that they are sensitive to small air movements. Furthermore, the use of permanent magnet generators, based on rare earth permanent magnets, results in lightweight and compact systems that allow low cut-in wind speeds. In this way, electricity can be generated with wind speeds as low as a few metres per second

To be more attractive for integrating into buildings, micro wind turbines are also being designed to be more visually attractive, without compromising their performance. Another objective is to reduce/eliminate noise associated with blade rotation and gearbox/generator noise. This can be achieved by using low-noise blade designs, vibration isolators to reduce sound and sound absorbing materials around the gearbox and generator. Lastly, simplifying wind turbine components/systems also adds to the attractiveness of wind turbine application and reduces maintenance costs. Efforts in this area include the integration of inverters into the nacelle (rotor hub) (EWEA, 2009).

Lastly, to lower the product costs, advanced blade manufacturing methods, such as injection moulding, compression moulding and reaction injection moulding, are being applied to reduce labour and increase manufacturing quality.

In terms of applications, development of wind home systems (WHSs), based on the idea of solar home systems (see Section 4.12), is a growing trend. A typical wind home system comprises a micro wind turbine, a battery, and various DC electrical appliances. Research shows that in coastal island areas with frequent windy conditions (e.g., Kutubdia and St Martin islands in Bangladesh), the application of WHSs is more cost effective compared with solar home systems (Khadem, 2006).

Application requirements

Micro VAWTs are often installed at locations with frequent windy conditions. Prior to installation of a wind turbine, it is important to collect wind data in the immediate vicinity of a building or installation site. Based on the wind data, a suitable type of wind turbine and suitable location can be determined to maximise the electricity generation. One important criterion is to match ambient wind conditions with a wind turbine's cut-in wind speed, rated wind speed and cut-out wind speed.

Prior to installation of wind turbine(s), especially in a large number, on an existing building rooftop, it is important to ensure the roof structure is strong enough to hold the additional loads. These include the weight of wind turbine(s) and vibration from wind turbine operation. Vibration absorbent technology should be applied in order to prevent damage to building structure and to reduce interior noise in the building. As wind turbines are usually installed on the high point of the building, prevention measure from lighting damage should be in place. Accessibility for maintenance should also be planned for.

Figure 4.13.2: Integrating micro wind turbines to the built environment in urban setting

Implementation status and market penetration

In recent years, wind turbine technologies have enjoyed strong market growth globally. The global average annual growth rate of wind power capacity from 2003 to 2007 was close to 25% (i.e., from 40,000MW at the end of 2003 to 94,000MW at the end of 2007) (EWEA, 2009). China is reported to be the largest market for small wind turbines (REN21, 2009). As a general observation, the market penetration for wind turbines in the regions near the equator is low, due to the small range of temperature change year round– a natural phenomenon that results in lower wind speed in compared to regions further away from the equator.

For micro wind turbines, the initial markets were villages and developments on off-shore islands and remote rural areas. In these areas, the cost of installing micro wind turbines can usually be justified when compared to the high infrastructure cost to extend the power grid or building a power plant. Taking Inner Mongolia as an example, there are already about 250,000 micro wind turbines installed, and the use of WHSs is considered a norm. The manufacturing capability in Inner Mongolia is about 40,000 units annually (EWEA, 2009). Micro wind turbine grid-connected systems have also found a foothold in residential and commercial buildings in urbanised areas. The European Wind Energy Association (2009) anticipates this market sector to expand rapidly, thanks to the trend of higher energy prices and increasing demand for on-site power generation.

Feasibility for implementation

Research and development is the initial step for large-scale implementation of building integrated wind turbines in a region that has no precedent for wind turbine application. In particular, what is required is local wind mapping to understand wind speed, frequency, and wind directions at various heights and various settings. This data is crucial to determine the feasibility and the suitable types of wind turbines to be implemented in a particular area. If the feasibility study shows positive results, with a feasible return on investment, supporting policies and financial mechanisms should be in place to make building integrated wind turbines commercially viable for large-scale adoption by building owners, developers and related professionals and trades. Supporting policies should include but are not limited to the follows:

1. Reducing or removing subsidies for fossil-fuel-based electricity supply.
2. Reducing or removing import tariffs on wind turbine components.
3. Clearly identifying power grid expansion plans (for rural and remote areas) and communicating these plans clearly to the public. This is necessary for building developers to calculate payback period in the decision making process to invest and implement wind turbine off-grid systems including wind home systems.
4. Setting up smart grid and incentivising feed-in tariff (in urbanised areas) as a platform to promote wind turbines for on-grid use.

In addition to the above incentivising policies, local building and construction authorities should regulate the installation of building integrated wind turbines in the following aspects:

1. Structure safety
2. Noise pollution control
3. Grid connection
4. Urban-scape design guidelines.

Another important factor for large-scale implementation of building integrated wind turbines is capacity building, especially in the following areas:

1. Technical knowledge to compute, simulate and deploy appropriate types of wind turbines at appropriate locations to maximise their performance and aesthetic integration with buildings and urban-scape
2. Installation skills and techniques for local workforce
3. Maintenance procedures for building owners and facility management personnel
4. Manufacture of micro wind turbines and related components. In this way, the products are locally available with low embodied carbon, and at the same time the local green economy is supported with new jobs creation and income sources.

Contribution to social, economic and environmental development

Wind power is a key component of renewable energy utilisation. Implementation of building integrated wind turbines contributes positively to the environment as a climate change mitigation option.

Wind turbine technologies, used in wind home systems in particular, contribute to social development by improving the quality of life to villagers in remote islands and rural areas, similar to that of solar home systems (see Section 4.12). These benefits include:

1. Better environmental health and reducing fire hazards by avoiding use of kerosene for lighting
2. Making information and entertainment accessible through the use of radio and television.

Building integrated wind turbines offer opportunities for local economic development, including:

1. Less financial burden to households due to lower electrical costs
2. Opportunities for households/building owners to sell surplus electricity back to the grid
3. New skills and job opportunities for the local workforce
4. Mechanism to grow the local green economy.

Financial requirements

Financial requirements for the implementation of building integrated wind turbines include investment and maintenance costs. Investment cost covers not only the products and their installation, but also feasibility studies and system design related activities. One of the most critical activities is to analyse (for existing buildings) and predict (for new buildings during design stage) the wind conditions on and around the building to determine the feasibility and location for installation.

The cost components of wind turbines vary in a wide range, depending on the type, capacity rating, and local availability. Return on investment depends greatly on the actual wind conditions and performance onsite, and partially on the incentive level of feed-in tariff and local electricity pricing.

Case study

Bahrain World Trade Centre, Manama, Bahrain

The Bahrain World Trade Centre is a good example of building-integrated wind turbines in a large-scale commercial building application. The high-rise building integrates three HAWTs, each with a 29m rotor diameter, into sky-bridges linking two 50-storey towers. The wind turbines are mounted at heights of 60m, 98m and 136m.

The shape of the towers underwent extensive wind tunnel testing and was refined to provide optimal performance of the wind turbines. The towers funnel, accelerate and direct the sea wind to flow perpendicular to the turbine rotor axis. In the design, provisions were made so that small cranes can be mounted on the three supporting bridges for maintenance of the wind turbines and replacement of their components.

Total cost for the building integrated wind turbines were reported to be around 3.5% of the total project cost. The three wind turbines generate between 1,100MWh to 1,300MWh annually, meeting about 11% to 15% of the building's electricity demands (Designbuilt-network.com, 2010).

4.14 Energy management and performance improvement

The technology

Once various energy efficiency measures have been deployed in a building, energy management and performance improvements can be put in place as a set of tools to:

1. Ensure energy systems' performance meet the design intention, through proper commissioning during building handover procedure.
2. Monitor, evaluate and manage the energy performance to optimise occupants' comfort and a building's functions, while maintaining energy efficiency, through Building Energy Management System (BEMS).
3. Improve the energy performance of the building through Energy Performance Contracting (EPC) by a qualified Energy Services Company (ESCO).

Commissioning originally referred to the testing and rectifying deficiencies of heating-ventilation-and-air-conditioning (HVAC) systems of a building to meet established standards prior to the owner taking over the building. Today, commissioning recognises "the integrated nature of all systems that affect a building performance, impact sustainability, workplace productivity, occupant safety and security" (US GSA, 2005). Commissioning is considered as a quality control process that presupposes correct functions and performances of all technical systems and building components during building handover. In many countries, commissioning is a mainstream practice and compulsory under building codes. Tools to assist commissioning activities have been developed and range from a simple checklist form to a sophisticated matrix form. The matrix organises various commissioning aspects against the stages of building development from design to operation. Various computational tools have also been developed to assist the commissioning activities. An example is the MQC_JP matrix developed for Microsoft Excel users. The matrix enables the storage of large number of data and easy navigation. MQU-JP matrix can be customised to suit a specific project (IEA, 2008).

Building Energy Management System (BEMS) is a computer based control system installed in buildings. BEMS integrates the monitor and control of mechanical and electrical systems within a building into an overall control and optimisation strategy related to energy, occupant comfort, etc. Systems and subsystems to be managed by BEMS include but are not limited to chillers, plant optimisation control, lighting features and dimmer controllers, indoor air quality control, plumbing and other electrical-related systems. BEMS has the capability to respond proactively to alarms and trace the sources of problems. BEMS also gathers, analyses and controls building performance data such as temperature, humidity, levels of carbon dioxide, room illumination, etc., of various spaces in a building. BEMS's components are generally laid out in a four-level system:

1. Sensors, switches, etc., at the field (equipment) level
2. Outstations and discrete controllers at the control level
3. Central station with a computer based control system at the operation level
4. Central station communication via gateways at the management level.

BEMS, in its most recent form, benefits from advanced development of intelligent/smart technologies and communications, such as wireless technologies. These technologies empower BEMS to extend its scope, such as optimising energy efficiency through interoperable services and dynamic control of multiple equipments and technological systems. Other advanced approaches include communication among sensors, context-aware, user-adaptive, prioritisation of information, etc. (European Commission, 2009). For example, lighting sensors from a room's daylight system can send signals of overcast sky to BEMS. The system then analyses data from motion sensors installed in the room to detect whether the room is in use, in order to decide to whether to automatically switch on supplemental artificial lighting. Such data are also used to determine whether air-conditioning in that particular room should be turned off or remain to be on.

Energy Performance Contracting (EPC) is a performance-based procurement method and financial mechanism for building renewal. The utility bill savings resulting from the installation of new building systems that reduce energy use are used to pay for the cost of the building renewal project. A 'Guaranteed Energy Savings 'Performance Contract includes language that obligates the contractor, a qualified Energy Services Company (ESCO), to pay the difference if at any time the savings fall short of the guarantee.'(EPC Watch, 2007). ESCO provides integrated solutions to achieve energy efficiency and thus energy cost reduction. ESCO's activities include:

1. Carrying out energy audits
2. Providing consultancy services to improve energy efficiency
3. Operating and maintaining installations
4. Facility management, energy management including demand monitoring and management
5. Modifying/upgrading electricity-consuming equipment
6. Providing energy and thermal energy supply from district heating/cooling, co-generation or tri-generation.

Payments to ESCO services are linked to the performance of the implemented solutions (KPMG, 2009).

Application requirements

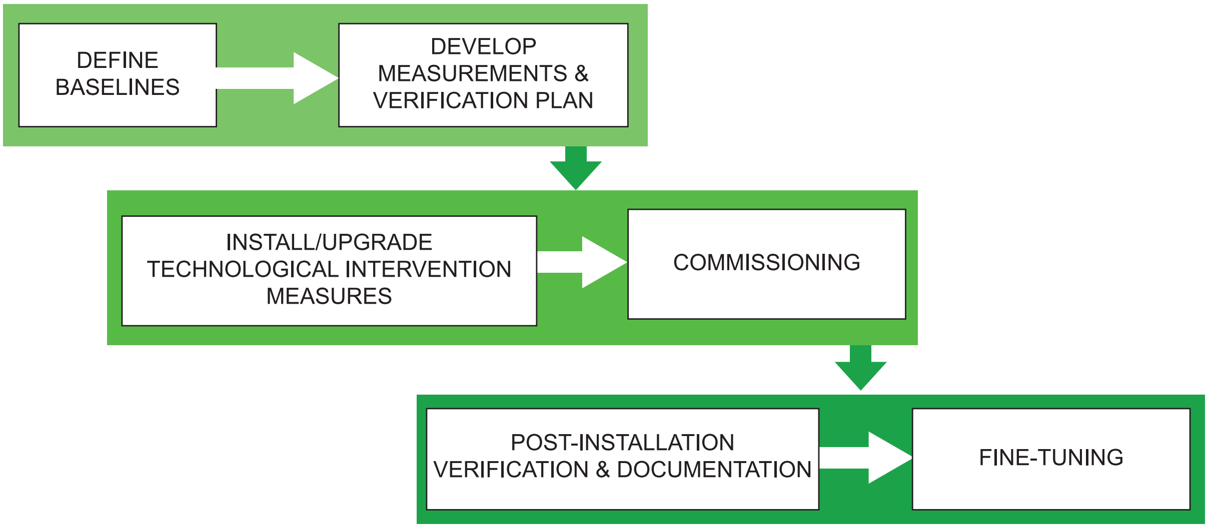
Energy management and performance improvement can be applied in all climatic contexts. The practices are most suitable for commercial buildings (offices, retails, hotels, etc.) and large-scale mixed-use complexes, in which the technological systems are complex and require a systematic approach to manage.

Good practices of building commissioning during handover normally include verifying performance against the intentions set at the early stage of building design, ensuring installations have undergone onsite inspection, that all technical systems have been tested and any faults have been rectified. Commissioning of advanced technologies/systems requires training operating/facility management staff and educating of potential users. A building user guide is also provided during the commissioning procedure to explain the operational procedures and functions of complex technical systems. Handover of complex and large-scale buildings often involves an independent commissioning agent. Third party involvement can help eliminate hidden deficiencies, which would otherwise not be detectable until the post-occupancy period (Lohnert et al., 2003).

While building commissioning is, in most cases,an essential part of a good building contract, BEMS and EPC require the support of building developers/owners. To optimise its potential and cost effectiveness, BEMS can be best incorporated during the design stage. The information can then be included in both drawings and specifications related to a building contract. During the building operating stage, BEMS requires personnel to operate and monitor. User interface and manually override functions have to be in place for possible intervention in case of system break down and/or emergency situations. BEMS can also be applied to existing buildings to monitor and subsequently optimise energy performance. BEMS is, in fact, one of the technologies that can be used by ESCOs to monitor and manage the energy performance of buildings.

ESCOs often start a project by defining the baselines: existing energy consumption patterns and rates, equipment inventory and conditions, occupancy, existing energy saving measures, etc., through surveys, inspections, spot measurements and short-term metering. After implementing technological interventions by the ESCOs, the baseline conditions are used for computing potential savings in energy consumption and monetary terms. Based on the baseline conditions, ESCOs develop project specific measurements and a verification plan. The plan includes specific technological interventions, their potential energy and monetary savings, verification methodology, maintenance schedule and cost, and payback period. After installing or upgrading the technological intervention measures, post-installation verification is deployed and often includes commissioning. This is to ensure that technological intervention measures are designed, installed, and tested. Post-installation verification methods can be surveys, inspections, sport measurements and short-term metering. Subsequently, ESCOs are often required to carry out periodic performance verification and submit the results in a report form, documenting the actual saving achieved. These activities also provide operational feedbacks, facilitating any necessary fine-tuning to the installed intervention measures.

Figure 4.14.1: Typical process of ESCOs



Implementation status and market penetration

Among the three practices and technologies discussed under energy management and performance improvement, building commissioning is the most feasible one to be implemented widely. Commissioning has been evolved from ad-hoc implementation of individual technological systems and equipment (such as air-conditioning systems) to include comprehensive whole-building commissioning. The tangible benefits of building commissioning have recently been appreciated and the practice has become popular in many parts of the world.

The implementation of BEMS is more common for commercial buildings than for residential buildings. BEMS is a proven and popular technology in developed countries. However, the technology is still not common to many users in developing countries, which are also huge potential markets for BEMS. Taking South Africa as an example, in the context of rising energy prices, BEMS, which has long been considered as an unnecessary capital expenditure, becomes justified as one of the effective technologies to reduce energy consumption in complex and large-scale buildings. It is reported that the South African market for BEMS earned revenues of US$19.2 million in 2008; this figure is estimated to reach about US$57.3 million in 2015 (Alternative Energy Africa News, 13/05/2010).

EPC has been implemented in many countries. The practice originated in North America, and has since been extended to other developed and economies in transition countries, and at the present is increasingly found in developing and even least developed countries. In 2002, the US market revenues for ESCOs reach about US$2 billion (Goldman et al., 2005). In Europe, Austria and Germany are the leading markets for ESCOs. In Austria, between 1998 to 2003, 600 to 700 public buildings were renovated using EPCs (Bertoldi et al., 2005). In Asia, especially in the context of rapid urbanisation with a large existing stock of retail space, offices and commercial buildings, EPC is becoming increasingly popular, especially services related to energy efficient air-conditioning. In Eastern Europe, EPC has been found to be popular in providing centralised heating, and combined heat and power plants, to address cold climatic conditions. Thanks to the support from international organisations,in Africa, EPC is also found in the area of off-grid renewable energy solutions. In South America, especially in the Caribbean where the tourism sector contributes significantly to GDP, ESCOs can be appealing to the hotel sector.

Feasibility for implementation

Implementation of energy management and performance improvement requires institutional supports and capacity building activities as catalysts. Subsequently, as experience has shown, the markets can become self-sustaining.

Building commissioning is more feasible for implementation. It can be included in building contracts as a common agreement between building developers and builders/contractors. This can be done as long as there is an agreement between the involved parties, in countries or regions without special institutional settings for commissioning – e.g., legal requirements to mandate commissioning in contracts for complex building types.

BEMS requires capacity building to train highly-skilled technicians to install and operate the system. The key capacity building areas include but are not limited to:

1. Knowledge of the individual mechanical and electrical systems, their installation, operation and maintenance requirements
2. Knowledge and analytical skills, in order to comprehend the optimisation of overall energy performance through inter-operable and dynamic control of individual electrical-related systems/equipment
3. IT skills to operate, manually override (when needed), and maintain BEMS.

A sound institutional setting, including a financing system, forms a good foundation for EPC services. For example, a non-subsidised electricity price and the availability of a feed-in tariff are good incentives for ESCOs to grow their renewable energy services - i.e., combined heat and power plant operated using renewable primary energy sources. In least developed countries, capacity building and financial assistance from international organisations will boost EPC services, which in turn help mitigate climate change and, at the same time, improve quality of life.

Contribution to social, economic and environmental development

Energy management and performance improvement contribute to environmental, economic and social development through:

1. Continuing energy efficiency from the building design stage to actual building operation, reducing life-cycle GHG emission from buildings
2. Monitoring and optimising the performance of buildings for both occupants' comfort and energy efficiency
3. Creating new jobs, offering additional green financing mechanisms, and supporting a low carbon economy through emerging EPC services.

The benefits of building commissioning include:

1. Ensuring good performance of technical and technological systems, and improving their life cycle
2. Increasing owners and occupants satisfaction by enhancing environmental health and comfort level
3. Reducing training and familiarisation costs for facility management staff

4. Lowering utility bills by being energy efficient, and improving building occupants' productivity. The operating cost of buildings with proper commissioning has been reported to be 8% to 20% below that of non-commissioned buildings (US GSA, 2005).

The key contributions of BEMS include:

1. Providing building owners/occupants with optimisation of energy usage,while maintaining indoor environment quality.
2. Offering early warning and detection of problems for the connected equipment and sub-systems, and ease of problem diagnostics.
3. Reducing energy consumption by providing real-time energy consumption for connectedenergy-consuming equipment/appliances. The IPCC highlights recent research indicating that BEMS can save energy consumption for space heating (up to 20%), for lighting and ventilation (up to 10%), and for overall building operation (5% to 20%) (Levine et al., 2007).

The main contributions of EPC are:

1. The opportunity to target and improve the energy performance of the large existing building stock.
2. The opportunity for existing building owners to have electricity-consuming equipment and systems upgraded and renewed. Replacing outdated energy-intensive equipments and systems with more efficient ones at no/low investment cost to the building owners.
3. A green financing mechanism that can unlock the financial bottleneck of large-scale implementation of energy-efficient and renewable energy technologies.

Financial requirements

The financial requirements for building developers/owners to implement energy management and performance improvements vary from a one-time cost for building commissioning, investment-operating-maintenance cost structure for BEMS, to no additional investment cost for EPC.

The one-time cost of building commissioning is often planned upfront and included in the specifications of a building contract. In more complex building projects, independent commissioning agents are often brought on board. Their fees are often borne by the developers/owners.

BEMS can be considered as a technological feature incorporated into a building. It, therefore, comes with investment, operating and maintenance costs. The investment cost varies depending on the sophistication of the BEMS, and the level of complexity, number and size of the mechanical-, electrical- and other sub-systems connected to the BEMS. The operating cost often includes the cost of electricity consumption from sensors, computers, and other electronic equipment related to the BEMS, as well as salaries for facility management personnel. A budget should also be set aside for maintenance costs related to repair and replacement of BEMS parts/components and upgrade of software and hardware.

EPC requires minimal or no investment-cost-sharing from the building owners. The cost to carry out energy audits and modifying/upgrading equipment and systems is, in most cases, borne by the ESCO. ESCO then gains a return on investment through monetary saving from electricity bills after the upgraded systems are in place. EPC benefits existing building owners, who receive new/upgraded equipment and systems without or with little investment cost. During the auditing and upgrading period, some disruptions to building operations are nevertheless expected.

Case study

The Lifestyle Home Garden Centre in Randpark Ridge, Johannesburg

The Centre is a mixed-use retail and office complex. When the Centre had plans to double its floor area, its application to increase the permitted electricity supply to be in proportion with the floor area expansion was rejected. The developer then had to rely on energy efficient measures for the expanded complex to operate 50% more efficiently. In order to manage the optimisation of all the various electricity loads, building management system technology was deployed. BMS was programmed to control and monitor the entire building's mechanical and electrical systems, including fire and security control. The BMS also helped safeguard the building energy demand not to exceed the permitted electricity supply. This is accomplished by identifying and shutting down non-essential loads that do not impact the core functions of the buildings. The R500,000 investment cost for BMS was paid back in less than a year(Imagine Durban, Ethekwini Energy Office & Ethekwini Electricity Department, 2009).

Gebhard-Muller School, Biberach, Germany

This vocational school building is equipped with BEMS connecting heating, cooling, ventilation, electric lighting and shading systems. Data is sent to BEMS through an extensive network of 2000 data points. The design intent was to achieve less than 25kWh/m^2 annually for heating and less than 100Wh/m^2 annually for primary energy. Building commissioning was included and its scope covered conceptual design all the way through construction, handover and the operation stage. The commissioning activities tapped into several methodologies, including:

1. Computational simulation to optimise the control strategy for the embedded heating and cooling system. Results show that a potential 35% energy saving can be achieved without negative effects to occupants' thermal comfort.
2. Functional performance tests have been developed for the identified crucial systems and components for building's energy efficiency, including the air handling units with rotary heat exchangers and heat pump systems.
3. Data visualisation to be available for two-year monitoring and recording.

The outcomes included high-level satisfaction from occupants in terms of thermal comfort and energy efficiency. The involvement of user and operation personnel in the design process was seen as a very positive attribute (IEA, 2008).

4.15 Behaviour change catalysts

The technology

An effective measure to reduce energy consumption in buildings is to deploy technologies that have the ability to influence occupants' behaviours towards a sustainable lifestyle and being less wasteful of electricity. The characteristics of this group of technologies are:

1. To make information and data related to energy consumption visible to the occupants
2. To make the benefits of being energy efficient tangible to the occupants, especially in monetary terms.

At present, key technologies, which can be considered as behaviour change catalysts, include:

1. Energy efficient appliances
2. Home area network (HAN), also known as smart home technologies
3. Pre-paid meters, which have been implemented in Africa countries as well as in parts of China.

While energy efficient electrical appliances and pre-paid meters are proven technologies and widely implemented, HAN is a rather new technology that has the potential for future large-scale applications.

Energy efficient appliances differentiate themselves from conventional appliances in terms of consuming less electricity for the same service and service quality. Key high-energy consuming appliances, such as air-conditioners, refrigerators, clothes washers, clothes dryers, water heaters, etc., are the main targets for energy efficiency improvement. In recent years, the energy consumption of standby and low-power-mode of appliances have been noted for their energy consumption. Their accumulative energy consumption globally accounts for as much as 1% of global CO_2 emissions and 2.2% of OECD electricity consumption (IEA, 2001). This have led to a worldwide race for research, development and production of energy efficient appliances. For example, between the late 1990s and the end of 2007, Japan's Top Runner Program – an initiative to upgrade appliance efficiency standards in Japan –saw the efficiency standards for various appliances raised by 15% to 83%, depending on the types of appliances (Brown, 2009).

Home area network (HAN) is a network within a home that connects electrical domestic appliances (i.e., HVAC, lighting, refrigerators, washing machines, water heaters, televisions, computers, etc.) to smart meters. The smart meters allow homeowners/tenants to monitor and manage their energy use and remotely monitor and control thermostats and other electric appliances through personal digital devices (computers, mobile phones, etc.).

HAN ranges from a simple in-home energy display unit to advanced energy management systems at the community and urban scale. Basic level in-home display units include programmable thermostats and automation functions for intelligent domestic appliances. They provide convenience for homeowners and also allow them to understand their energy usage patterns. At the advanced level, in-home display units are connected to smart meters for wider energy management at the community and urban scale through smart grid systems. Some key application capabilities are:

1. Gather data about homeowners/tenants lifestyles and patterns of everyday activities
2. Analyse the above data and synthesise the optimal operation parameters for appliances (e.g., temperature census, automatic on or off times) to optimise energy consumption and yet suit a particular lifestyle
3. Carry out two-way communication with smart grid (where applicable) to exchange real time energy demand from the consumer end, feed into the grid any surplus energy, and receive electricity supply dynamic pricing (i.e., peak vs. off-peak). At this level, HAN can also assist in optimising electricity demand side that is cost effective for the homeowners and reduces peak load demand to the communal energy supply infrastructure.

HAN technologies and application capabilities are still under research and development to overcome barriers for widespread implementation. These barriers include:

1. Lack of a common protocol to facilitate the compatibility in communication among various HAN technologies/products and between HAN and a smart grid system
2. Lack of guarantee to prevent the possibility of data leakage that compromises homeowner/tenant privacy
3. Poor market penetration and user acceptability at the present.

Pre-paid meters have been implemented mainly in Africa as an innovative alternative to conventional electricity meters. Electricity meters measure the amount of electricity used in a building or spatial units of a building over a period of time, and displays the measurement in kilowatts per hour (kWh). The popular application of conventional electricity meters is to facilitate the reading of the amount of electricity already consumed, so that utility companies can compute the fee and charge customers accordingly. However, this procedure is reversed in the application of pre-paid meters, in which consumers are required to pay up-front for a certain amount of electricity prior to consuming it.

In other words, pre-paid meters are used to regulate the amount of electricity to be supplied to consumers. In application, consumers purchase tokens from vending machines located at convenient locations in the village/town. The tokens can then be inserted into electricity dispensers installed at each household. More advanced applications include online vending systems, which can be used in combination with electronic banking. Such systems help reduce operational costs for the utility providers, which can be translated to lower electricity costs for consumers.

Application requirements

Energy efficient appliances pose neither special spatial nor additional technical requirements for their applications, as they are typically no different in size and shape compared to conventional ones.

Home area network (HAN) can be easily applied at domestic level, which is to network the electrical appliances with an in-home display system and personal digital devices (e.g., internet-accessible computer, mobile phone, etc.) for monitoring and remote control. The key equipment includes:

1. 'Smart' power points, which make the connected appliances identifiable and controllable by the network
2. A gateway device with wireless connection to the 'smart' power points to gather information about the energy consumption of the connected appliances
3. An interactive display unit, which shows the data gathered from the gateway device and allows users to monitor energy usage or even customise energy profiles for the appliances. The wireless information in the display unit can also be viewed and controlled from personal internet-based devices, such as computers and mobile phones.

Where smart grids are available, the advanced comprehensive application of HAN to address energy management at the community and urban scale can be made possible, through two-way communication between HAN and the smart grid via a smart meter installed at each household.

Pre-paid meters require mainly the credit and/or vending system set out by utility providers. At the building and household level, the technical requirements are similar to those necessary for the installation of a conventional meter. The key requirements include:

1. Protecting meters from weather, especially rain,
2. Locating meters away from potential contact with water or heat sources
3. Being accessible for maintenance.

Implementation status and market penetration

Energy efficient appliances have already established a strong foothold in developed countries and have become popular in developing countries. This is due to rising energy prices, public consciousness about energy consumption and government mandates. Furthermore, the market potential for energy efficient appliances is high, thanks to the growing number of voluntary energy efficiency labelling schemes, mandatory minimum energy efficiency standards, and mandatory energy information labelling for appliances in many local and national governments. One example is the Mandatory Energy Information Labelling Scheme by the China National Institute of Standards (CNIS). The scheme was launched in 2005 to cover only two products. In 2007, the Scheme was extended to cover three key appliance types including air conditioners, refrigerators, and clothes washers. The CNIS went on to implement the Mandatory Energy Efficiency Standards, which cover most residential and commercial appliances, lighting, heating and cooling equipment (Zhou, 2008). In brief, it is anticipated that the use of energy efficient appliances will become mainstream, under the market forces and the incentives of supporting policies.

Figure 4.15.1: Green label for energy efficient appliances

Home area networks are at the infancy stage of market testing and penetration. The potential market for HAN is limited to the high-end residential sector. This is due to the high costs and high-tech requirements.

Pre-paid meters were first established in the UK, and launched in 1992 in South Africa to support the nation-wide electrification programme. Pre-paid meters are popular in South Africa, where the technology is reported to enjoy the highest market penetration. Furthermore,South Africa is the world leader in pre-paid meter manufacture. Their applications are extended to other countries in Africa and to other regions, such as Turkey and China. In fact, China was also reported to be the largest market for pre-paid meters in 2006 (ABS Energy Research, 2006).

Feasibility for implementation

Energy efficient appliances are often analysed or verified through product energy labelling systems, which can be initiated by governmental agencies or reputable NGOs. Examples include Energy Star by the U.S. Environmental Protection Agency and the U.S. Department of Energy, and Singapore's Mandatory Energy Labelling Scheme for key domestic appliances (i.e., air-conditioners, refrigerators and cloth dryers) by the National Environment Agency. Though labelling schemes, consumers can easily compare the energy efficiency of different products of similar capacity, as well as the energy and monetary savings from operating more efficient products. To strengthen its application, product energy labelling schemes are often integrated with local green building rating tools (where available).

Home area network is still at the market testing stage, and requires much more effort prior to large-scale implementation. First of all, technology providers have to establish a common set of standards and protocols for compatible integration of various products, and further fine tune their products to be friendly and appealing to end-users. Secondly, demonstration projects and awareness building programme to the general public should be in place at the initial market penetration stage. Thirdly, more research and development is needed to bring down the cost, so that HAN technologies can also be used by middle- and lower-income end users. From the institutional setting aspect, a simple form of electricity dynamic pricing – i.e., different electricity tariffs for peak- and off-peak consumption – will be an initiative for large-scale implementation of HAN. Once these are in place, more sophisticated dynamic pricing – e.g., hourly-based or real-time based pricing – can be developed to encourage homeowners to become even more energy conscious.

Pre-paid meters are most feasible in assisting electrification of rural communities at the early stage. The implementation requires good collaboration and communication among the power plant operators, utility providers, local government, and members of the community. Each of these stakeholders have distinct, but interrelated roles. For instance, the local government puts in place clear policies and provides incentives. Power plant operators and utility providers work out economic feasibility and provide the infrastructure and operate the system. Members of the community are updated with knowledge about how the system works and are empowered with basic maintenance procedures. The more advanced form of pre-paid meters, such as online vending systems, can be implemented in the communities where majority of households are networked.

Contribution to social, economic and environmental development

While all the three focus technologies – energy efficient appliances, HAN and pre-paid meters – contribute directly to domestic energy savings and thus GHG emissions reductions. The contribution of these technologies to social development is significant because they provide a catalyst for mass behaviour change toward a more sustainable lifestyle. For example, HAN allows home owners to view user-friendly real time data on the energy consumption of appliances and equipment. This offers a catalyst for people to take decisions and actions leading to energy savings. Furthermore, HAN, through automated two-way communication, provides a platform for electricity providers to improve their operational efficiency.

Pre-paid meters were originally used to address social issues of energy theft and tampering with electricity meters. Soon after, the application of pre-paid meters required consumers to plan ahead for their electricity demands. Subsequently, they serve as constant reminder to consumers to use energy wisely.

The increasing popularity of energy efficient appliances also serves as a catalyst for green economic development. HAN, together with smart grids at the community and urban scale, has a great potential to become vital means for the implementation of dynamic pricing of electricity supply, which in turn becomes another catalyst to further strengthen energy saving practice. HAN improves the match between electricity demand and supply and, as such, helps reduce peak demand, leading to reduced electricity supply constraints and the need for power infrastructure expansion.

Financial requirements

Energy efficient appliances, in many cases, cost more than conventional appliances. This is due to the incorporation of new energy saving technologies, as well as their relatively early market penetration stage. However, the cost of energy efficient electrical appliances is projected to be lower than that of the non-energy-saving appliances, thanks to future economy of scale, possible regulation intervention (e.g., carbon tax), and their progress toward being the norm among consumers. The encouraging fact is that most energy efficient appliances in the market can have their investment returned after a period of time through energy savings. With the trend of higher energy prices, the return on investment period of energy efficient appliances becomes shorter, providing further incentives for their application.

Home area network requires homeowners to invest upfront to install the related equipment. Other costs include minor costs related to their energy used for the in-home display unit, and for maintenance. In addition, a small budget needs to be set aside for system and software upgrades, as the technologies are still at the fine-tuning stage.

Pre-paid meters require financial investment from a utility provider to lay out the distribution infrastructure, install vending machines, and operate the system. A small upfront investment is often required from the consumers to install pre-paid meters in their homes. Subsequently, consumers will have to budget themselves to pre-pay for the electricity to be consumed.

Case study

Pre-paid metering project, Chittagong, Bangladesh

The project is a pilot programme to implement pre-paid meter use in Bangladesh. The programme is being carried out by the Bangladesh Power Development Board with support from the German Government. The pre-paid meters are installed in participating residents' rooms, apartments or houses. The residents can pre-pay their desired amount of electricity and receive numeric passwords at ten local vending centres. After keying the password into the pre-paid meter, electricity is dispensed for consumption. The meter will automatically cut off the flow of electricity when the credit is used up. However, if the credit is used up during the night or over a weekend or public holiday, the meter continues dispensing electricity, and the residents can then pay back the deficit amount on the next business day at one of the vending centres. Positive feedback has been received from the participating residents. These include the satisfaction with the ability to control their own consumption and budget, and having no hassles with disconnection and reconnection. The power companies also benefit from better cash flow (thanks to receiving upfront payment), lower overhead (i.e., saving manpower from meter reading or billing), avoiding disputes over non-payment, and better electricity load management. It is anticipated that the initial investment costs of the project will be recovered in 6 or 7 years (Deutsche Botschaft Dhaka, 2010).

4.16 Community based energy services

The technology

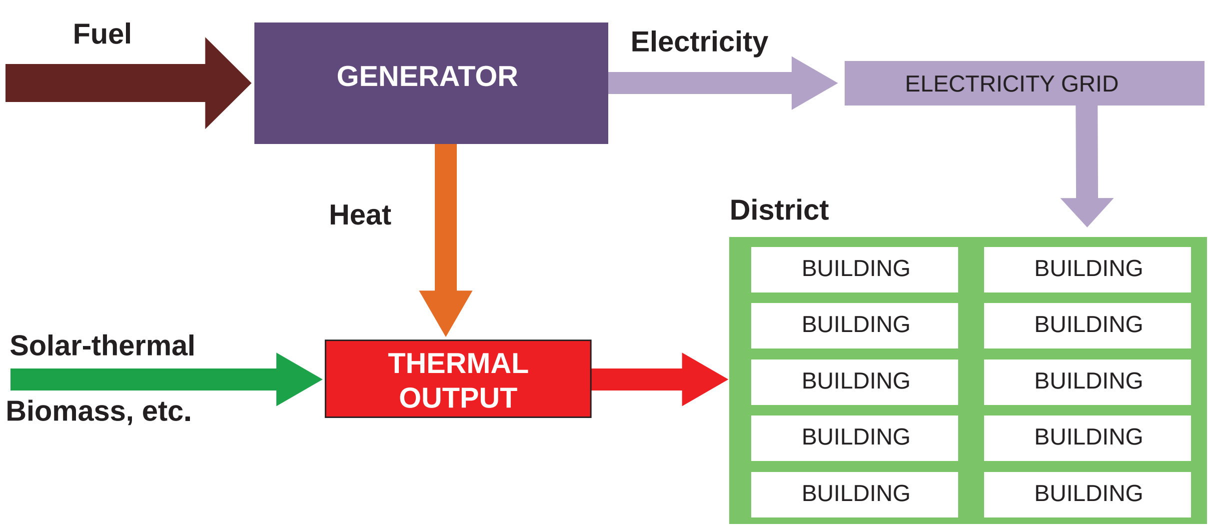
Community based energy services, as the term suggests, provide heating, cooling and renewable energy to more than one building. It is an alternative to the use of individual energy related systems in each building. The services often consist of:

1. Centralised generation and supply of heating/cooling as well as energy from renewable sources
2. A distribution network to bring heating/cooling to buildings within the community
3. Other installations (air handling units, and controls) within individual buildings.

Community based energy services are often found in two forms – district heating/cooling and combined heat and power (CHP) generation.

District heating/cooling refers to combined heating/cooling at a centralised location, and distribution of heating/cooling to the buildings of a defined community, through a piping network, for space and water heating or space cooling. The energy required for heating/cooling can be tapped from waste heat from nearby industrial processes (if available) and/or renewable sources such as solar thermal and geothermal energy. District heating/cooling may provide higher efficiency for heating/cooling, compared to the use of individual systems in individual buildings. It also provides flexibility to a building's owners/tenants to purchase and use only the required heating/cooling.

Figure 4.16.1: Diagrammatic illustration of district heating/cooling



Due to the economy of scale of centralised heating/cooling installations, district heating/cooling systems can apply various forms of energy efficient practices in a cost effective manner. One such practice is the use of thermal ice storage. Ice is generated during off-peak hours and stored for chilled water generation use during peak hours, helping reduce electricity peak load. By shifting a part of the chilling load to off-peak hours, chiller equipment requirements and size can be reduced closer to the average load. This leads to higher chiller operating efficiencies and lower cost per unit of cooling. Another practice is the use of sea water as an indirect source for district cooling systems in tropical coastal regions. The constant cool sea water temperature in these regions can act as a heat sink to cool condenser water-based district cooling systems, reducing electricity load demand.

Combined heat and power generation (CHP) operates with a similar concept to district heating; however, heat is sourced from the heat waste of power generation in the same system. Typically, power generation is on average only 35% efficient with 65% of the energy potential being waste heat. CHP can reduce the efficiency loss by recouping heat waste as a form of thermal energy for space heating/cooling, and as such, can increase plant efficiency to 90% or more (KPMG, 2009). Conventionally, waste heat recovery and power generation of CHP plants is from cogeneration in plants burning fossil fuels.

However, an increasing number of CHP plants are based on renewable sources such as solar thermal, biogas,micro-hydro or cleaner sources such as biomass. Natural gas and fossil fuels can be used only as make up and back up sources. CHP systems are also being integrated with other renewable energy harvesting technologies, forming a hybrid system. For example, a CHP system utilising biogas is suitable for agriculture-based communities. Biogas (usually in the form of methane) is harvested from organic solid waste and manure which has undergone anaerobic digestion. Organic solid waste and manure are day-to-day wastes produced from community and farming by-products. They can be used as resources for CHP to co-generate heat and electricity. The digested manure can also be used as fertiliser for agricultural production.

The availability of various heating-cooling technologies – e.g., compression and absorption chillers – has led to the development of combined cooling and power generation systems. In these systems, waste heat from a CHP process is converted to chilled water and is transmitted to individual buildings in communities for space cooling purpose. Such developments allow wider and more flexible applications of district heating/cooling and combined heating/cooling and power generation in various climatic regions and seasons.

Application requirements

Community based energy services can be grouped into two application categories – high-density and lower density settings. In high-density settings, district heating/cooling is more feasible, as it can serve a large pool of community members in a small serving radius. In the high-density urbanised setting, the implementation of a CHP system is less feasible, due to the fact that: (1) energy generation is less crucial since electricity is readily available from the grid, (2) space constraints for a co-generator in combination with other renewable energy generation facilities such as biogas, and (3) less accessibility to renewable energy sources such as biogas and biomass, which would need to be transported to the site. CHP systems are, however, more feasible in lower density settings at urban fringes or agricultural villages and towns. In these areas, renewable energy sources are more readily available within the community itself, e.g., biogas from farm waste and manure, biomass from farming by-products and gardening waste, etc.

For both district heating/cooling and CHP systems, there are five main application requirements. Four of which are the main components: centralised plants, a heating/cooling distribution network, installation in individual buildings and metering. The fifth requirement is maintenance.

Centralised plants produce heating/cooling through boilers/chillers, recover waste heat through co-generation, or tap into waste heat from nearby industrial processes or power plants. Solar thermal technology can also be deployed for thermal energy generation. Where heat waste is available but cooling energy is needed, heating-cooling conversion technologies are required. Thermal energy is usually stored and transmitted in the form of hot/chilled water.

Heating/cooling distribution networks transfer thermal energy from a centralised plant to individual buildings within a community. The distribution network includes pipes and pumps. Pipes are often made of steel or copper, and are thermally insulated. They are often run underground to save on-grade land space and receive additional thermal insulation of earth. Leak detection systems and corrosion protections are required for underground piping. Pumps create pressure to circulate the thermal medium in the piping network of individual buildings. Afterward, the thermal medium is circulated back to the centralised plant, where it is recharged with thermal energy. Variable speed pumps are recommended for energy saving. The pumps should have low noise levels to prevent noise transfer through the thermal medium into the buildings.

Installations in buildings. Because thermal energy is generated at a centralised location, installations in buildings are simpler than the use of conventional full heating/cooling systems within individual buildings. The installation requirements include a heat exchanger, piping, valves, and control system. Control systems are similar to those used in conventional individual heating system – i.e., the same type of room thermostats, thermostatic radiator valves, and time switches or programmers (Energy Saving Trust, 2007). Similar to individual heating/cooling systems, tenants must understand how to use their heating/cooling controls to optimise thermal comfort and energy efficiency.

Metering is essential to monitor and ensure the efficient operation and usage. Data from the meter are useful for any necessary adjustments to the system's components, in terms of capacity, to allow better operational efficiency. Meters should also be installed at an individual end user's premises, not only to calculate fees to be charged but also to provide consumers with a direct incentive and to avoid wasting the purchased energy (Energy Saving Trust, 2007).

Maintenance requirements include preventive maintenance checks (including leakage), monitoring and reporting a system's performance.

Implementation status and market penetration

As a general observation, district heating has larger market penetration compared to district cooling, due to the more severe impact of cold weather compared to that of hot weather. The main markets for district heating are in Europe (including Eastern Europe) and Northern Asia. As of 2007, district heated floor space reach 108.8 million square metres including 41% of households in the Czech Republic, 8 million square metres in Slovakia, 38.16 million square metres (serving 70% of households) in Latvia, and over 3 billion square metres in China (Euroheat & Power, 2007). Nevertheless, the use of renewable energy resources and waste heat for district heating and implementation of CHP have significant potential to expand. In Slovakia, for example, renewable energy sources account for only 4% of the total installed district heating capacity. The remaining energy sources are coal and coal products (91%), and natural gas (5%) (Euroheat & Power, 2007).

Feasibility for implementation

Key activities leading to expanding implementation of community based energy services include setting up suitable investment and financing mechanisms, research and development, consulting with prospective energy and thermal energy users, and capacity building for maintenance staff.

Investment and financing mechanisms determine the feasibility for implementation, due to the initial large investment cost of a community based energy service system. This is followed by research and development, especially to identify energy sources (e.g., locally available waste heat from industrial processes, biomass and biogas).

User consultation is important to gain common understanding, expectations and co-operation. Consultation can be held in several sections, during a feasibility study, planning and design of a system and the construction and operational stages. The agenda should covers issues such as siting of the centralised plant, choice of equipment and control systems for individual buildings, charging system, procedures to rectify faults and feedback from users.

Capability building is also necessary, especially in developing countries to improve the system performance at minimum cost, and to train a local maintenance workforce with technical skills to install, monitor, identify faults in, and to repair the systems.

Contribution to social, economic and environmental development

The use of community based energy services can lead to many benefits related to environmental development. District heating/cooling systems can be more thermally efficient compared to that of many isolated small systems in individual buildings. District heating, for example, can provide up to 60% of heating and hot water energy demands for 70% of families in Eastern European countries and Russia (OECD/IEA, 2004). Furthermore, the operation of a centralised plant is more optimal in terms of energy efficiency, renewable energy deployment, and maintenance personnel. The IPCC's Fourth Assessment Report (Levine et al., 2007) draws attention to examples of district heating system tapping heat sources from:

1. Sewage waste heat in Tokyo, Japan and Gothenburg, Sweden
2. Geothermal heat in Tianjin, China
3. Waste heat from incineration in northern Europe.

CHP, on the other hand, can be operated on biogas, which is sourced from the organic waste generated by the community it serves. The products of CHP include both electricity and its generation's by-product (heat) and thus makes better use of energy resources. The combination of a biogas anaerobic digester and a CHP co-generator also offers better sanitation solutions for rural communities, reduction of odour and flies, prevention of water pollution due to waste dumping, and improved environmental health. Furthermore, sludge from a bio-gas digester can be used as compost for landscaping or agricultural production.

In social development terms, community-based energy services help create a sense of community and strengthen social coherence within a community. In economic terms, the use of community-based energy services offer owners of individual buildings:

1. Savings on capital cost for installing boiler/chiller plants
2. Savings on building space and maintenance cost for boiler/chiller plants
3. Savings on ongoing capital expenses to upgrade boiler/chiller plants
4. Flexibility, monitoring ability and controllability of thermal energy usage
5. With these, community based energy services become a form of catalyst for energy conservation behaviour.

Financial requirements

The main financial requirements for community based energy services include initial capital/investment cost, operational cost, and maintenance cost. All the cost components are high, due to the large-scale service application of the system. The actual investment cost of CHP and district heating/cooling varies depending on the systems, regions and whether the components are locally available. For example, the cost for a CHP including an anaerobic digester (to feed biogas to the CHP operation) with a capacity of 370kW is approximately US$8.5 million for a US installation in 2002 (North West Community Energy, 2002). A biomass–based CHP with a capacity of 2-3MW cost about Euro 1.2 million in Finland in 2001 (Kuntatekniikka, 2001).

Case study

Klaipeda, Lithuania

The district heating system in Klaipeda, Lithuania has a centralised plant operated using geothermal energy. The plant capacity is 43MW, enough to supply heat energy for the entire city (Ekodoma, 2004). At the plant, geothermal water at a depth of 1,135m and at a temperature of 380C is pumped to the surface and increased in temperature to 700C by an absorption heat pump. The heat pump is driven by water heated to 1750C by a boiler located in the plant. The 700C-temperature water is then supplied to a district heating distribution network. At times when hot water consumption is low, the surplus heated water is stored in a thermal water reservoir for peak-period use. The discharge water at 110C is filtered before being returned to the same layer of earth at a depth of 1,135m underground.

Jindrichuv Hradec, Czech Republic

Two independent district heating systems, serving 15,000 inhabitants in Jindrichuv Hradc, were modernised. The original oil-based steam district heating was switched to natural gas and biomass-based (wood waste) hot water system with a small cogeneration unit. The outcome provided a reduction of CO_2 emissions by more than 20% and a 68% reduction in sulphur dioxide, nitrogen oxides and fly ash emissions. The air quality in the town and neighbouring region improved significantly as a result (Zenman, 2003).

4.17 Sustainable community design and practices

The practice

As the concept and practices of a sustainable built environment have evolved over the years, it is increasingly recognised that the scope should be expanded beyond individual buildings to the community scale. Sustainable community design and practices refer to planning, designing, building, managing and promoting social and economic development of communities to meet sustainable development objectives.

Sustainable community design is often referred to those that relate to the physical planning for a new community. The key players are master planners, architects, engineers and other environmental professionals, who plan and design infrastructure, public facilities and buildings. The physical built environment will then serve as a base and facilitator for the newly established community to practice sustainable development lifestyles and initiatives. Sustainable community practices involve initiatives, organisation and management of both existing and new communities gearing towards sustainable development goals.

Sustainable community design and practices have been developed from conceptual ideas at the early stage to refined models and frameworks, through the experience gained from practical experiences around the world.

The current accumulation of global experiences shows that any community, regardless of income level, can work toward a sustainable development vision. At the very basic level, sustainable community design and practices can focus on:

1. Providing, rectifying and/or improving the physical built environment, sanitary and infrastructural services,and maximising the renewable resources available at the local context – e.g., sun, wind, rain, and vegetation.
2. Offering alternative means to generate incomes from the environment-friendly economy, such as ecotourism, local food production, waste recycling, etc.
3. Enhancing social conditions and community ties through joint-community projects and educational programmes.

This model, termed a low income sustainable community model, is the most suitable one for lower income communities with a vision for sustainable development.

For mid- to higher-income level communities, sustainable community design and practices include item (a) plus the following areas of focus:

1. High quality of life, such as sporting facilities, sustainable transportation facilities, local availability of organic food, and accessibility within walking distance to amenities such as retail stores, schools, parks, etc.
2. Community coherence and a low crime environment.
3. Community pride and identity, achievable by making community projects, such as renewable energy technologies, a landmark for a carbon neutral community.

Figure 4.17.1: Sustainable transportation facilities in Nankang, Taiwan

Many success stories of sustainable communities, at the lower- and higher-income levels, have been reported and have been published widely.

Application requirements

Sustainable community design works with, and makes full use of natural and climatic conditions. These include being responsive to sun, wind, rain, and vegetation when planning an energy efficient and comfortable environment for a community.

Responding to the local sun path at the community planning level takes into the account:

1. Provision for building layouts oriented north/south, and constraints for buildings with long west-facing façades.
2. Sunlight accessibility to individual buildings, especially during winter months. This is achievable through provision of minimum spacing between buildings to avoid overshadowing on windows.

For example, in China's northern provinces, residential buildings are required to be orientated not more than 200-250 from being directly south-facing. Furthermore, minimum building spacing is required, so that all residential units can have at least 3 hours of access to sunlight per day.

Planning sites in response to local seasonal wind characteristics will contribute towards creating good micro-climatic conditions for a community, including thermal comfort in communal spaces and in individual buildings. The planning strategies include:

1. Planning for taller structures and/or densely planted trees on the boundary facing the prevailing winter wind direction, so that the communal public spaces and/or other buildings in the community can be protected from cold wind.

2. Using building shapes and layouts to channel and allow prevailing summer breezes to pass through open communal spaces and other buildings in the communities.

Rain offers a community water resource, which is particularly important for regions where fresh water is a scarce resource. If well planned, harvested rainwater provides alternative fresh water source for a community. However, if not well managed, rainwater may become polluted making it a source of environmental health hazards, such as breeding ground for mosquitoes. Good community design and practices include:

1. Harvesting rainwater from building rooftops for usage at the building level (see section 4.9).

2. Capturing and channelling run-off water to provide natural cleansing mechanisms, including a network of leading to a retention pond. Here the cleansed water can be used for non-potable usage, such as local farming and landscape irrigation.

Figure 4.17.2: Natural cleansing mechanisms for storm water management

Good practices in landscape ecology are also important factors in community design. They include:

1. Protecting the existing nature and ecosystem of a site. In the planning process, it is good practice to identify and preserve the existing ecological network, which is densely vegetated and rich in biodiversity.

2. Planning for green corridors connecting various green patches to create a continuous green network within and beyond the community to nurture biodiversity.

3. Promoting and nurturing native vegetation, which usually requires minimum maintenance and saves water resources (as no additional irrigation required).

4. Providing open green spaces, such as parks and communal gardens that are easily assessable and within walking distance for all community members.

Figure 4.17.3: Community garden provides community bonding opportunities, and is part of open green space for visual relief to this high-rise high-density housing setting

Sustainable community practices especially for existing communities, often include: rectifying and enhancing the environmental performance of the physical built environment, building a sense of community, upgrading the community quality of life and developing skill sets gearing toward a green economy. The required steps towards sustainable community practices often take a bottom-up approach and include:

1. Discussions with members of the community to understand their existing lifestyles, daily activity patterns, and wish lists for improving the living experience in the community.

2. Encouraging members of the community to participate in all activities, including identifying areas for improvement, planning and design of the physical built environment and operating and monitoring sustainable-related activities.

3. Empowering members of the community in all decision-making processes and instilling a sense of ownership and pride in communal activities.

Implementation status

Sustainable community design and practices have been widely implemented worldwide. Evidences for this in developed countries are substantiated by the launches of community versions of existing green building rating tools, such as LEED for Neighbourhood Development, BREEAM Communities, Green Star Communities, etc.

In developing countries, sustainable community design and practices are also widely implemented, evidenced by the expanding name list of sustainable communities and reports of successful stories in the press, especially in Africa. Low-income sustainable community models are proven to be useful in improving livelihoods in many rural areas of developing and least developed countries, and in rebuilding the communities affected by post-natural disasters (e.g., the 2004 tsunami affected communities in South-East- and South-Asia).

Feasibility for implementation

Feasibility for implementing sustainable community design and practices requires a large amount of preparation and coordination effort, especially at the initial stage. Steps towards implementation, especially for low-income sustainable community models, include:

1. Involving as many stakeholders as possible to appraise the status of existing communities, in terms of the physical built environment, and of social and economic conditions. The stakeholders include all residents of the communities, local government, agencies, and business networks as well as related non-government agencies.
2. Designating individual(s) as champion(s) for sustainable community programmes. This person(s) should be endorsed and supported by members of the community and local government authorities.
3. Identifying, together with stakeholders, key needs and objectives. All decisions should be based on consensus building.
4. Creating a vision and a workable roadmap to achieve the vision, based on the key needs, objectives and contextual constraints, (Smart Community Network, 2003).
5. Developing a set of indicators to benchmark and monitor the progress.
6. Identifying and communicating with supporting partners, including (a) financial support and expertise from international agencies, regional and national governments, and (b) potential customers or service receivers from a community's activities.
7. Starting with the most feasible and economical activities, which are able to generate an income stream, that can support subsequent and more challenging activities.
8. Monitoring and improving the progress of the activities with regular feedback sought from all stakeholders and partners.

Contribution to social, economic and environmental development

Sustainable community design and practices contribute to environmental development through:

1. Designing with regard to local climatic conditions, including sun path and wind conditions, to create a comfortable micro-climate for both communal spaces and individual buildings in a community.
2. Harvesting rainwater as an alternative additional fresh water resource for non-potable usages, e.g., landscaping and farming irrigation. This helps avoid or reduce groundwater extraction and depletion.
3. Promoting native vegetation, preserving existing ecological network and nurturing biodiversity.

Sustainable community design and practices contribute to economic development of a community by:

1. Reducing and eliminating poverty for lower-income communities, while upgrading their skills for employability in green economy sectors.
2. Facilitating a sustainable local green economy, for example, through eco-tourism and local food productions.

Lastly, sustainable community design and practices, especially the model for low-income community, contribute to social development by:

1. Providing members of the community opportunities to learn new skills and pick up new knowledge
2. Generating community ties and sense of ownership
3. Reducing crime
4. Generating additional income sources
5. Improving quality of life.

Financial requirements

The implementation of sustainable community design and practices for low income communities often requires financial support by international agencies, e.g., Habitat for Humanity, the World Bank, United Nations Agencies, NGOs, with backing from local governments. Financial support is required at the initial stage for a kick-off, usually related to the design and implementation of activities related to the built environment and infrastructure development. Low income sustainable community design that is based on the principles of maximising available renewable resources, as detailed in the 'Application Requirements' section, does not often incur any additional significant investment cost. Furthermore, successful community activities often find themselves a sustainable income stream generated from the return on investment, which can help maintain their current activities, and even allow the community self finance their subsequent activities.

Case study

Urban Green Renewal Project, Samora Machel, Philippi, South Africa

This project was initiated and run by Green Communities, an NGO, to promote a sustainable green living environment in an existing low-income settlement, Samora Machel. The objectives included beautifying the physical built environment, providing local food production, improving income opportunities for residents and enhancing environmental health through sustainable practice intervention.

At the onset, Green Communities worked closely with residents in the community to find out the main needs and kind of initiatives the community would like to pursue. The findings identified two primary concerns: food security and income sources. These findings led to the establishment of initial activities related to urban farming related to the production of organic vegetables in netted food tunnels (Green Communities, 2010).

In order to make the programme successful, Green Communities linked the community with Cape Town's upmarket restaurants, which agree to purchase all the organic vegetables produced from Samora Machel. The community is looking forward to an annual income of R200,000 to R300,000, some of which will be use to fund back to the community programmes and the rest shared equally between the 35 family members of the project (Palitza, 2010).

With the prospect of an income stream from the urban farming project, Green Communities planned to launch a recycling and waste management swap shop in the community. The facility would facilitate the resident's practice of recycling recyclable waste, such as glass, paper and plastic, which could be exchanged for general household items and clothing. The organisation also secured a promise from Waste Plan, the largest onsite waste management company in South Africa's Western Cape Province, to employ 60 Samora Machel residents¸ who would have to undergo two six-week waste management courses. This programme was to fulfil the second major concern and need of the community.

In parallel to these activities, Green Communities also worked closely with local governments to initiate a large-scale urban greening programme in Samora Machel. The activities would include planting indigenous trees and plants in all schools and childcare centres, creating new parks, gardens, and engaging residents in organic composting and worm farming activities to produce fertiliser for urban greening programmes (Palitza, 2010).

5. Implementation of Mitigation Technologies and Practices

5.1 Prioritisation of mitigation technologies and practices at the national level

National conditions as determining factors

The detailed technologies and practices presented in Chapter 3 and 4 as mitigation typologies from the building sector have to be prioritised to suit each country's circumstances. Each country has its own specific set of conditions, which presents advantages and opportunities for implementing some mitigation technologies and practices, and pose constraints for others. Key conditions are:

1. **Geographic settings.** These include the climatic conditions of difference areas (e.g., coastal, inland, highland or valley location),determine the suitability of mitigation technologies and practices. For example, in a hot and humid tropical region located in a valley, technologies to cool and ventilate the built environment prevail, heating technologies are not applicable, and wind turbine technologies may not be suitable due to calm conditions. Other considerations include the availability of local resources and materials, which can support the long-term plan to build up and expand the local manufacturing capacity of certain mitigation technologies.

2. **State of economic development.** This is useful to determine the technologies and practices that are meaningful in economic terms. For example, in least developed countries, the focus should be on low- to no-cost mitigation technologies, such as renovation and the innovative use of traditional building materials and techniques. Implementation of such technologies can be implemented in the immediate- and short- term, before progressing to more sophisticated technologies that require higher capital and skilled workforce investments.

3. **State and trend of urbanisation.** It is relevant to identify the prevailing national urbanisation status, i.e., rural settings, rural areas subject to urbanisation, urbanised areas, and the urbanisation trajectory. If the country has many areas that are rapidly urbanising, mitigation technologies and practices relevant to new buildings will take higher priority. If the country has large rural areas with a low projection of urbanisation, off-grid renewable technologies can be in the high priority list.

4. **State of the built environment.** In particular, the quantity and quality of existing building stock needs to be identified. They can be classified in terms of the estimated percentage of the existing building stock expected to undergo major renovation, the estimated percentage of the existing buildings to be replaced in the short term, and the projected quantity of new buildings to be developed in the short-, medium-, and long-term. This will help to prioritise the technologies and practices, which are suitable for new buildings, or the renovation of existing buildings.

5. **Strength of existing industries.** Taking into account the established industries presents immediate opportunities for creating mitigation technologies and practices with a high success rate. For example, countries with a strong existing cement production industry and shipping industry have

the opportunity to develop and implement green concrete. This is because the abundant availability of by-products from the shipping industry (e.g., fly ash, granulated blast-furnace slag) can be utilised by the cement production industry to substitute the use of carbon-intensive Portland cement.

6. **Availability of existing workforce and experts.** The available skills in-country can be tapped into and/or upgraded easily to implement the targeted mitigation technologies and practices. In this way, the relevant technologies can be prioritised for implementation with a minimum of capacity building and training. For long-term development, national strategies for workforce development should also be considered.

7. **Social and behaviour norms.** These should be taken into account when prioritising mitigation technologies and practices. This helps to gain support from stakeholders, achieve better take-up rates,and helps avoid negative outcomes by not introducing irrelevant technologies and practices. For example, in countries where natural ventilation for buildings is the norm (which is made possible by favourable climatic conditions), the prioritisation of air-tight technologies is not rational, because these technologies are not as relevant for building designed with natural ventilation as they are for air-conditioned buildings.

8. **Indigenous technologies and practices, with mitigation potentials.** These should be identified, if they exist in the country. An example is the traditional application of wind towers in Middle East countries. This indigenous technology serves as stepping stone for innovative application to advanced passive solar design technologies, as discussed in Section 4.1. Therefore, if the country has indigenous technologies and practices that have mitigation potential, priority should be given to their application.

Decision-making framework for prioritisation

In order to facilitate the National TNA Team to prioritise mitigation technologies and practices that are relevant to their own country, there is a need to establish a decision-making framework for comparative analyses of all the possible mitigation typologies and practices. The framework is a matrix, and established based on the multi-criteria analysis approach, as recommended by the UNDP's Handbook for Conducting Technology Needs Assessment for Climate Change (UNDP, 2010).

This matrix outlines the various mitigation technologies and practices against the determining factors. These factors are based on the national conditions as detailed in the section above, and the availability and practicality of the technologies/practices in a temporal scale – i.e., short-, medium- and long- terms. UNDP (2010) elaborates:

1. *Short-term technologies have been applied commercially with a proven reliability in a comparable market context*

2. *Medium-term would be pre-commercial in that given market context (fiveyears to full marketing) and a long term technology would still be in a research and development phase or a prototype.*

Furthermore, the potential for South-South transfer offers the potential for long-term success and upscaling of the technologies and practices beyond national boundaries. Such long-term considerations contribute not only to the efforts of the building sector globally in climate change mitigation, but also the domestic economic development. Table 5.1.1 outlines the decision-making framework for prioritisation in its generic form.

Table 5.1.1: Decision-making framework for prioritisation of mitigation technologies and practices at the national level

Mitigation typologies	Technologies and practices	Geographic Settings	State of Economic Development	State &Trend of Urbanisation	State of the Built Environment	Strength of Existing Industries	Availability of Existing Workforce & Experts	Social & Behaviour Norms	Potential Indigenous Technologies & Practices	Short-term Availability	Medium-term Development	Long-term South-South Transfer Potential
Passive Solar Design	Site Selection											
	Design Responsive to the Site Conditions											
	Design Responsive to the Sun											
	Design Responsive to Wind											
	Use of Thermal Mass Materials											
Advanced Passive Solar Design	Renovation and Innovative Use of Traditional Building Materials & Techniques											
	Passive House Design and Technologies											
Technologies Enhanced Passive Solar Design Performances	Life Cycle and Integrated Design Process											
	Building Envelope Thermal Insulation											
	High Performance Building Façade Systems											
	Daylight Harnessing Technologies											
Active Design	Highly Efficient Heating, Ventilation and Air Conditioning Systems											
	Efficient Lighting Systems											
	Water Efficiency Technologies											
Low-Carbon and Carbon-Sequestration	Carbon-Sequestration& Low-Carbon Building Materials & Products											
	Greening & Building Integrated Greenery Systems											

Mitigation typologies	Technologies and practices	Geographic Settings	State of Economic Development	State &Trend of Urbanisation	State of the Built Environment	Strength of Existing Industries	Availability of Existing Workforce & Experts	Social & Behaviour Norms	Potential Indigenous Technologies & Practices	Short-term Availability	Medium-term Development	Long-term South-South Transfer Potential
Onsite Renewable Energy Generation	Solar Technologies											
	Building Integrated Wind Turbines											
Monitoring and Occupants' Feedback Loop	Energy Management & Performance Improvement											
	Behaviour Change Catalysts											
Beyond Individual Buildings	Community-Based Energy Services											
	Sustainable Community Design and Practices											

Key principles for applying the decision-making framework

When applying the decision-making framework to prioritise mitigation technologies and practices at the national level, the following key principles should be carefully considered:

1. Reduce GHG emissions in large quantities in a short timeframe, starting with the most feasible, moving on to more sophisticated technologies and practices
2. Be appropriate to the country's specific context and circumstances
3. Be complementary with other national development objectives, including quality of life, pollution control, social wellness, high employment rate, higher gross domestic product, etc.
4. Strengthen the social and economic performance of the country.

In addition to the above, the National TNA Team should be aware of the level of familiarity of the mitigation technologies/practices. This can be a bias factor during the prioritisation exercise. For example, unfamiliarity with or a lack of knowledge of certain technologies/practices could lead to reduced or low application, because their strengths, weaknesses, opportunities and threats from previous implementations have not been comprehensively understood. To further explain this phenomenon, UNDP (2010) quotes Winskel et al., (2006) that "organisations operate in embedded socio-technical networks and tend to re-invest in established competences: disruptive technologies (e.g., renewable energy) rarely make sense to incumbents, so their development tends to be left to small outsider organisations."This may lead to the National TNA Team making decisions on technologies/practices prioritisation without sufficient background information. The strategy to overcome this potential issue is that the National TNA Team should appoint a 'technology champion' for each unfamiliar technology or practice. The role of the technology champion is to seek further information for the rest of the team members and arrange for familiarisation activities, such as technical study tour, seminars, and experience-sharing by global experts.

5.2 Technology implementation strategies, stakeholders and context

Stakeholders

After the mitigation typologies are prioritised at the national level, implementation strategies can be formed. Good strategies can only be derived from good understanding of the building sector's stakeholders. These topics and the related issues will be identified and discussed at this session.

There are generally 10 key stakeholders in the building sector. Each has, conventionally, its own main interests and concerns, which are summarised in the table below:

Table 5.2.1: The building sector's stakeholders and their main concerns (based on Wallbauma et al., 2010).

Key stakeholders	Main interests and concerns
Investors	Return on investment, economic feasibility
Manufacturers/suppliers	Energy supply, availability of natural resources
Banks/financial institutions	Return on investment
Contractors	Materials and energy supply, skill workforce availability
Planners/designers	Knowledge, creative and efficient application of technologies
End users/owners	Well-being, economic feasibility, lifestyle
Public authorities	Regulations and control
NGOs and civil society	Social equity, access to information
Research and education	Technologies and knowledge
Media	Democratic sharing of information

As climate change is high on the international community's agenda, the building sector in many countries is going through a paradigm shift. The objective is to unleash the building sector's huge mitigation potential, while improving the sustainable development of the built environment. The role of the stakeholders, therefore, needs to be reviewed. The UNEP SBCI, at the 4th Annual General Meeting in 2009, convened representatives of the building sector stakeholders, who reviewed and proposed the commitments and priority actions to reduce GHG emissions from the building sector. These commitments and priority actions are superimposed onto the conventional main concerns of stakeholders in Table 5.2.2.

Table 5.2.2: The building sector's key stakeholder, their conventional concerns, and commitments to address climate change (with reference to UNEP SBCI, 2009)

<table>
<tr><th>Key stakeholders</th><th>Main concerns</th><th>Actions & commitments (to address mitigation)</th></tr>
<tr><td>Investors</td><td>Return on investment, economic feasibility</td><td rowspan="5">1. Work with governments to develop policies that make a difference and act as agents of change.
2. Work to introduce a carbon trade mechanism for buildings.
3. Renovate buildings to maximise a reduction in their emissions and to improve climate adaptability.
4. Demonstrate technology and know-how frontiers on their own buildings and rented offices.
5. Move to holistic and system solutions for buildings.
6. Dedicate research and development to climate-neutral, zero-net buildings
7. Educate the supply chain.</td></tr>
<tr><td>Manufacturers/ suppliers</td><td>Energy supply, availability of natural resources</td></tr>
<tr><td>Banks/financial institutions</td><td>Return on investment</td></tr>
<tr><td>Contractors</td><td>Materials and energy supply, workforce</td></tr>
<tr><td>Planners/ designers</td><td>Knowledge, creative and efficient application of technologies</td></tr>
<tr><td>End users/ owners</td><td>Well-being, economic feasibility, lifestyle</td><td>1. Create market demand for energy efficient buildings that deliver a better quality of indoor environment and promote a better quality of life.</td></tr>
<tr><td>Public authorities</td><td>Regulations and control</td><td>1. Establish national regulations to make energy efficiency investments mandatory in new buildings and in renovation of existing buildings.
2. Conduct inventories of energy consumption, energy efficiency and emissions from the national building stock to establish baselines and set performance goals to reduce GHG emissions.
3. Establish an energy efficiency in buildings investment fund that can be used to promote initial investments and renovations for energy efficiency in buildings. Such a fund could be financed through taxation of energy use above the national average, and/ or by redirecting investments in additional energy production that will be avoided by reduced energy demand in buildings.
4. Support the inclusion of measures in the new global climate change treaty that encourages investments in both new building and building renovation projects that reduce or eliminate emissions.
5. Include in the technology transfer framework/measure, support to capacity building to enable and increase energy efficiency in existing and new buildings.
6. Support the development and reform of all flexible mechanisms to encourage investment in and reduction of GHG emissions from building operations.
7. Retrofit all publicly-owned buildings for high-level energy efficiency and large GHG emission reductions.</td></tr>
</table>

Key stakeholders	Main concerns	Actions & commitments (to address mitigation)
NGOs and civil society	Social equity, access to information	1. Advocate, communicate and share information. 2. Train professionals and tradespeople working in the building sector and educate the next generation of professionals to implement sustainable building principles and practices. 3. Facilitate leadership and bridging efforts. 4. Help monitor quality assurance and standards of low GHG emissions building performance. 5. Help communities adopts climate-friendly behaviours and lifestyles.
Research and education	Technologies and knowledge	1. Renovate and build schools to reduce GHG emissions and foster long-term responsible lifestyles. 2. Implement interdisciplinary curriculum and research on energy, GHG emissions and social performance. 3. Collaborate to provide a data repository and ongoing analysis of the climate impact of buildings. 4. Develop curriculum and tools for building energy efficiency and environmental responsibility. 5. Develop regional and sub-regional centres of excellence, focusing on buildings' role in climate change mitigation and adaptation.
Media	Democratic sharing of information	1. Widely promote the urgency and necessity of realising mitigation potential from the building sectors. 2. Disseminate the technical information, lessons learnt and experiences in implementing mitigation technologies and practices in the building sector.

Strategies

The effective implementation of mitigation technologies and practices requires a new paradigm shift in the roles and performances of stakeholders, as outlined in the previous Section. Stakeholders commonly share a commitment to working in collaboration with other stakeholders, creating a nexus of partnerships. The key partnerships are identified below. It is important that these are incorporated into the strategies for implementing the mitigation technologies and practices:

1. **Integrating top-down and bottom-up approaches:** Top-down approaches refer to governmental policies. They can be in the form of incentives and mandatory requirements. They have the ability to influence the operations of other building sector's stakeholders, especially those in the private sector. Bottom-up approaches include initiatives and efforts from individuals (such as homeowners, architects engineers, developers, and investors), companies, professional associations and so on. Top-down approaches set direction at macro scale, and bottom-up approaches are accumulative actions from the implementation level. In order to create a realistic and effective implementation plan, top-down approaches require inputs from the stakeholders who will implement the changes

or strategies. Likewise, bottom-up initiatives need to have their mitigation contributions recognised and supported by other stakeholders. Innovation and the further development of the mitigation technologies and practices are also required for a conducive environment to prosper (e.g., supportive policies, good business prospects, etc.). The integration of top-down and bottom-up approaches is a powerful strategy to address the segmentation and fragmentation barriers to realising the GHG emissions reduction potential in the building sector. It can also be a good strategy to address the financial disincentives barrier, especially to address any split economic interests among the stakeholders in the building sector. For example, with governments' strong commitment and clear direction on reducing GHG emissions from the building sector (top-down approaches), the banks and financial institutions can confidently roll out green loan services to building developers and owners to invest on the relevant mitigation technologies and practices. This bottom-up approach, in turn, reinforces the governmental policies for future launches of more ambitious and innovative policies related to GHG emissions reduction in the building sector.

2. **Public-Private Partnership (PPP):** Similar to integrating top-down and bottom-up approaches, PPP combines the strength of the public and private sectors to unlock the financial barrier (both the first-cost and operation expenses) of implementing large-scale and high investment capital mitigation technologies and practices. An example is the large-scale deployment of building-integrated wind turbines (BIWT) in the immediate term, but with the long-term plan to establish local manufacturing capacity, and export the products and technical services in the form of South-South transfer. In a typical PPP arrangement, the public sector provides supportive policies and incentives, while the private sector invests or co-invests to develop and implement a project. The first-cost investment will be recovered by the private sector under an agreed time frame, and governed by clear and upfront agreed policies. PPPs alleviate governments from heavy first-cost investment, while reducing risks (in the form of supportive governmental policies) for the private sector to invest.

3. **Partnerships with research/education institutions:** This can be in the form of public sector and/or private sector partnering with research/education institutions to widely deploy and innovatively develop the mitigation technologies and practices. In such a partnership, the research/education institutions benefit from funds made available from the public and/or private sector. In return, the research/education institutions spearhead innovation and the further development of mitigation technologies and practices appropriate to the local context. They also offer skilled workforces and professionals for the implementation of mitigation technologies and practices.. The benefits of these partnerships can be reaped in the medium- to long- term, but the partnerships need to start in the immediate term.

4. **Partnerships with end users and local communities:** Implementing mitigation technologies and practices will not be successful without the acceptance and participation of end users and communities. Partnerships with end users and communities can be carried out in the form of public awareness programmes and campaigns. Hosts for these activities can be the public sector (i.e., relevant governmental agencies), private sector (e.g., companies promoting energy efficient products), NGOs, educational institutions, media (e.g., T.V. programmes, magazine articles, newspapers reporting the benefit of energy efficient technologies and best mitigation practices, etc.). Awareness-building activities can also help to address the consumerism aspiration and rebound effect barriers to the GHG emission reductions in the building sector, as highlighted in Section 2.3.

5. **International partnerships:** International partnerships always have something to offer, whether they occur at the infancy or the mature stage of the implementation of mitigation technologies and practices. For countries at the mature stage, the technical skills, technological advancement and implementation experiences become valuable resources for South-South transfer. For countries at the

infancy stage, it is beneficial to tap into the rich source of technical experiences and implementation strategies for well-informed approaches and support that are available from the countries at the mature stage.

By using these key collaborative and coordinated strategies, it is expected that the mitigation potentials of the technologies and practices (as detailed in Chapter 4) can be optimised.

Context

The approaches and strategies to engage stakeholders at an appropriate time can only be optimally deployed through understanding the country's context, social, economic, cultural and stage of development. Even within a country, there can be different contexts. For example, there can, in general, be three contexts in terms of the built environment status. These settings are: rural, semi-rural areas subject to urbanisation, and urbanised. Due to the specific characteristics and requirements of different contexts, each of the three settings poses different challenges, opportunities, and requirements. From a generic observation:

1. In rural settings, the immediately applicable mitigation options are technologies and practices related to passive solar design, advanced passive solar design, technology-enhanced passive solar design performance, low carbon and carbon sinks,onsite renewable energy generation, and sustainable community design and practices. The challenges often include poor accessibility to technical knowledge and information, and financial limits for deploying onsite renewable energy technologies. Community bonds are often strong in rural settings, and can be tapped onto for effective awareness campaigns.
2. In urbanised settings, suitable mitigation technologies and practices are those pertinent to high density built environment, such as building integrated greenery systems, grid-connected photovoltaic technologies, and community-based energy services. These more technical-sophisticated technologies are also supported by the availability of higher-skilled workforces, existing research institutes, etc.
3. In semi-rural areas subject to urbanisation, there are opportunities to implement a wide range of mitigation technologies and practices to newly built buildings. Among many implementation strategies, it is crucial to incorporate considerations and programmes for the existing workforce from other sectors (often agriculture) to switch to, and/or upgrade their skills in, the areas of energy efficient buildings and related technologies. In this way, implementing mitigation technologies and practices can also help alleviate the pressure and impacts caused by social and economic changes by providing opportunities for employment.

5.3 Practical implementation steps

Building on the previous section's discussion on the context, stakeholders and broad strategies, this section outlines general practical steps to implement mitigation technologies and practices. These steps are:

Institutionalise the taskforce

The segmented and fragmented nature of the building sector requires a sophisticated institutional setting to address the barriers to coordinating the various stakeholders to implement mitigation technologies and practices. A specific taskforce should be institutionalised as a key governance body to look specifically into the implementation of mitigation technologies and practices in the building sector. This taskforce must be inter-governmental and comprise various related governmental agencies and departments. They should include those dealing with buildings and construction control, urban development control, park and greenery control, environment and pollution control, resources management, industry development, finance and tax, etc.

We take as an example,the promotion of the mitigation technology of building integrated greenery systems (Section 4.11). The park and greenery control agency can take the lead in providing application guidelines (such as suitable plants and species recommendations),monitoring the implementation progress, and monitoring the performances (such as the trend towards biodiversity). The building and construction control agency can provide construction guidelines, monitor construction quality, and put in place safety requirements for the installation of the systems. The urban planning agency can coordinate and promote the application from larger urban scale perspectives (such as greenery connectivity, biodiversity corridors, addressing urban heat island mitigation at hot spots, etc.) and incentives such as the possibility for additional allowable building floor areas, etc. The finance and tax agency can look into facilitating financial incentives, such as grants and tax exemptions for professional development and technical training courses. Such collaboration between inter-governmental agencies will provide a strong institutional setting, which supports the private sector and building owners to green their buildings.

In addition to the presence of inter-governmental agencies, the taskforce membership should also include:

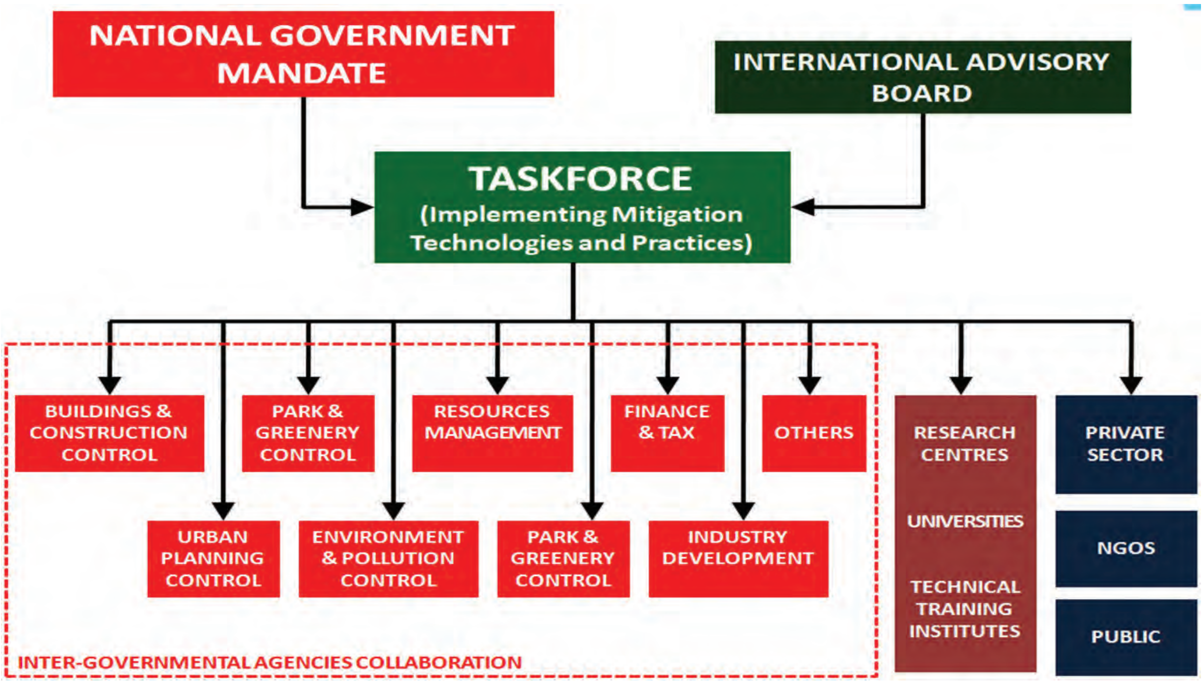
1. Representatives from local research centres, universities, and technical training institutes, which contribute to the strategies for detailed technical application, local workforce training and professional development

2. Representatives from the private sector, NGOs and the public, who provide inputs to the policy making process, and feedback on the effectiveness of the policies.

It is advisable for the taskforce to be guided by an international advisory board, comprising outstanding experts in the implementation of the targeted mitigation technologies and practices. The members of the international advisory board contribute not their wealth of experiences at the infancy implementation stage, as well as their wide networks and connections to bridge the local practices with global trends, development, and potential markets for exporting of the technologies/practices at mature implementation stage.

Figure 5.3.1: Organisational structure of a generic taskforce for mitigation technologies and practices.

Identify the gaps and the vision



One of the immediate tasks of the taskforce is to identify the gaps between the local implementation status of the targeted mitigation technologies/practices against international benchmarks, and to develop a vision for the implementation and development.

With the inputs from the international advisory board, the taskforce can carry out a comprehensive global survey of the implementation status of the mitigation technologies/practices. Equal emphasis should be given to successful and unsuccessful cases. Consideration should also be given to:

1. Analysing important success factors
2. Extracting lessons learnt from unsuccessful cases.

In parallel to the global survey, the taskforce should also gather knowledge from the local context in relation to the targeted mitigation technologies/practices. The taskforce can also consult with local stakeholders about the prospect of large-scale deployment and implementation of the targeted technologies/practices. This will help the taskforce better understand the perspectives, needs and concerns of all local stakeholders.

Superimposing the global best practices against the local context, the gaps in implementation status, strength, weakness, opportunities and threats of the targeted mitigation technologies and practices can be identified. To fully bridge these gaps is a long-term goal, based on which, the long-term vision for implementing the targeted mitigation technologies and practices can be formed. The long-term considerations, in turn, will inform the formation of the medium-term objectives, and ultimately the short-term plan and immediate actions.

Create an action plan

An action plan is necessary at the early implementation stage. A good plan will guide the macro deployment and implementation of technologies/practices in a feasible manner, yet can also be ambitious. The action plan should take the local context into consideration and set actions and targets in the short-, medium- and long- term. In general, the action plan can include the following:

1. Assess the availability of resources in terms of materials and skilled workforces for immediate start-up, and define achievable targets in the short-term
2. Scale up the technologies' take-up rate through raising awareness and various forms of incentives. These are also known as stakeholder buy-in strategies at the infancy implementation stage, and to make economic sense of the mitigation technologies/practices in the short-term
3. Deploy strategies for the implementation and development of the technologies/practices to be independent from incentives and to be self-driven by creating economic forces and demands in the medium-term
4. While the implementation of the mitigation technologies/practices is gradually being scaled up and normalised, deploy policies and strategies to build up manufacturing capacities for South-South transfer, and promote innovation through research and development to improve the performance of technologies and practices.

Set energy efficient building standards

Setting energy efficient building standards has been widely put into practice in both developed and developing countries to foster the implementation of all relevant technologies/practices, and to engage stakeholder participation. These standards can act as both a benchmarking and a monitoring tool. In addition, they can be applied to set the direction, as well as the moving targets for the building sector and its supply chain.

Implementing effective energy efficient standards for building scan help level the playing field for all stakeholders in the building sector. These standards should start with realistic minimum energy performances that are achievable without incurring high additional costs to building owners, developers, professional and other related technical and service providers. The compliance with the prerequisite mitigation typology – passive solar design –as detailed in Chapter 3, can provide a good starting point, due to that achieving these requirements does not incur additional costs, nor require high-skilled and trained technicians.

Demonstrate the application of mitigation technologies and practices

At the early stage of implementation, demonstrating how the targeted mitigation technologies/practices are installed and operated provides useful data on technical and economic feasibility. Demonstration projects provide not only the business cases but also lessons learnt for all stakeholders, including those involved in the projects.

In most cases, demonstration projects are initiated by the public sector. Public buildings, such as schools, hospitals and social housing, can provide a good range of building types to demonstrate various technologies/practices. It is useful to start with selected projects as pilot projects. Once the business case is established, the targeted technologies/practices can be rolled out on a large scale for all public buildings. In this way, the public sector can take the lead and be the market stimulator to reduce the building sector's GHG emissions. Encouragingly, in recent times, more and more demonstration projects have been initiated by the private sector as part of marketing strategies, and by universities or research institutes as part of their research and development activities.

Establish mitigation technologies information centres

Demonstration projects are often generic. For example, certain technologies can perform best under certain conditions, which are often set up in demonstration projects. However, individual buildings are contextual specific and can have different conditions, requirements, opportunities and constraints in terms of applying various mitigation technologies/practices. Information centres can be set up, in addition to demonstration projects, to provide specific practical advice and technical assistance for stakeholders. Advice given could include specific products, brands, technical specifications, where to find a company to do the work and what (if any) financial help is available (UNDP & GEF, 2010).

Train local workforce and build capacity

Scaling up the application of the targeted mitigation technologies/practices beyond demonstration and pilot projects cannot be achieved without locally available skilled workforces and experts. Therefore, strengthening local technical training institutes and universities is a priority at this stage. In rural areas and semi-rural areas subject to urbanisation, it is also important to tailor training programmes for workforces from other sectors (such as agriculture) to make career shifts to those in the building sector. In this way, realising GHG emissions reduction potential can also positively impact local social and economic issues.

Create a conducive business environment

At this point, it is essential to create a conducive business environment around the targeted mitigation technologies and practices and their spin-off business activities. Such an environment can be created through tax incentives, grants and incentives for incubation, recognition of best practice through awards, etc. These will stimulate the rise of local entrepreneurs and champions in the innovative application and development of the targeted mitigation technologies and practices.

Once the local stakeholders attain competency in the targeted technologies and practices, the taskforce can carry out the plan for knowledge transfer, and for exporting the technologies through South-South transfer.

Promote innovation and the further development of mitigation technologies/practices

When the minimum energy efficient standards and the application of the targeted technologies/practices become the norm and easily achievable by all the local stakeholders,energy performance standards should be raised to achieve higher mitigation targets. It is important, however, for these standards to allow for, and encourage, the use of innovative technologies and practices, beyond those detailed in Chapter 4.

Furthermore, partnerships between public sector, private sector and/or universities and research centres do not have to stop at the application level, but should extend to further improvement and further development of the targeted technologies/practices.

Put in place monitoring and feedback mechanism

The taskforce is strongly advised to develop means to monitor the progress made in the implementation of the targeted mitigation technologies and practices, as well as monitoring GHG emissions reductions achieved. They can be in the form of mandatory periodical audit reports from large-scale buildings that are equipped with the targeted mitigation technologies and practices. They can also be in the form of monitoring the macro energy consumption by buildings in the implementation areas/neighbourhoods/towns/cities/regions.

The taskforce should also establish a feedback mechanism when implementing the planned action plan. The triggering factors for the feedback mechanism can be the periodically-quantified GHG emissions reductions, as well as feedback from participating stakeholders. The action plan should be flexible so it can be adjusted and improved, able to respond to the feedback mechanism. In this way, the action plan can be carried out with resilience to address the dynamic nature of the local context.

6. Conclusions

The building sector, as unfolded in the earlier Chapters, has large impact to the global environment, and also vast potential for climate change mitigation. The sector consumes a large proportion of the global energy supply, and accounts for a large percentage of GHG emissions. The prospect to reduce GHG emissions in the sector is enormous, especially through improving the energy performances in building. Thanks to the widespread influence of buildings to many aspects of our life, reducing GHG emissions in the sector comes with many opportunities to improve the quality of life, health, other environmental, social and economic development for users, local communities, towns, cities, countries and beyond.

As a modest contribution to optimise the above opportunities, this book has identified the key mitigation options available, analyses the various mitigation technologies and practices in details, and discusses about their implementation. It is, however, noted that implementing these mitigation options in isolation will not reap the expected result. As highlighted by UNDP & GEF (2010),"Large savings can be achieved by optimising the entire building system rather than improving elements individually. This can only be done at the beginning of the building's life or during major renovations. The rest of the energy consumption is linked to the building use, through the performance of equipment used in the building (e.g., boilers, HVAC system, lighting, electrical appliances, etc.) and the behaviours of the people who use them (choice of temperature, turning off unused lights and appliances, etc.)"

The building sector has large influence to many other aspects in our lives, e.g., well-being, health, social, economic, and other environmental impacts. Therefore, in addition to the buildings' holistic and life-cycle approach, mitigation technologies and practices must be implemented in sync with the overall sustainable development goals and strategies of local community, town, city, country, region and even the global community. This approach has been the guiding principle to the selection and organisation of the mitigation typologies, which are from the most feasible to more sophisticated levels for implementation, as detailed in Chapter 3.

The establishment of the Decision-making Framework for Prioritisation of Mitigation Technologies and Practices at National Level (Section 5.1) is another application of the guiding principle. The Framework aims to direct the prioritised mitigation technologies and practices to be in line with the national sustainable development trajectory. It does so by making the implementation of the prioritised mitigation technologies and practices part and parcel of the strategies to support short-, medium- and long terms social and economic growth, as well as improving the well-being and quality of life for the community and individuals.

The technologies and practices implementation strategies (Section 5.2) highlight how partnerships between and among the various stakeholders can be instrumental to optimise the potential of GHG emissions reduction in the building sector, through focusing on the connectivity among the triple bottom line of sustainable development (Cam, 2011). In other words, the effective implementation of mitigation technologies and practices requires an integrated approach that involves in all the stakeholders to deploy institutional, financial and workforce competency development strategies in a concerted manner. By so doing, the key barriers to realising GHG emissions potential in the building sector can be overcome.

The practical implementation steps (Section 5.3) suggest step-to-step actions to implement the mitigation technologies and practices to meet the intended objectives. It is important for the National TNA Team to note that the recommendations are generic, and can, at best, serve as general guidelines. The detailed implementation at the country, city, or local community level must be carefully contextualised to be appropriate to their specific circumstances to deliver the expected outcomes.

With the consideration of sustainable development at macro scale, the mitigation technologies and practices are analysed and discussed with defined objectives (Chapter 4). For each individual technologies and practices, the detailed discussion includes analyses about the contributions (to both climate change mitigation and other environmental, social and economic development), and details of the technical, contextual and feasibility requirements for implementation.

In brief, this book aims to provide detailed understandings to the key available mitigation technologies and practices in the building sector as the base for countries to carry out Technology Needs Assessment and develop Technology Action Plans. The mitigation technologies and practices are studied with technical-based analyses and careful considerations to the implement-ability. The implementation aspects include these to establish policy framework, feasibility to build up local capacity, potential to create and meet local market demands, and the possibility for South-South transfers.

The discourse about implementations has also been extended beyond their technical realm, reaching into boarder implementations of sustainable buildings. Truly sustainable buildings refer to those that are able to enrich our senses in daily interaction with the built and natural environment, and thus convey the beauty of sustainable living and practices to their occupants, stakeholders and public at large. This important quality sublimes sustainable buildings beyond the mere physical and building performance obligations, into the spiritual realm of leading sustainable lifestyle and practices (Cam, 2005). This is the additional but essential conditions and benefits for implementing mitigation technologies and practices. These will set the backbone for nurturing sustainable lifestyle and behaviours of the building occupants and communities, which are also strengthened by educational programmes and public campaigns to raise awareness from the public sector, NGOs and media. Such a systematic approach will put the building sector in a better position to materialise its enormous mitigation potentials, and improve the quality of the built environment for living, learning, working and playing.

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Appendix I
Summary Sheets: Mitigation Technologies and Practices

<table>
<tr><th colspan="6">Renovation & innovative use of traditional building materials and design</th></tr>
<tr><th>Associated technologies and practices</th><th>Contextual applicability</th><th>Critical application requirements</th><th>Feasibility for implementation</th><th>Financial requirements</th><th>Contribution to triple bottom line</th></tr>
<tr><td>Earth-related building materials</td><td>Rural areas where suitable soil types are available.</td><td>Understand local soil types and characteristics.

Produce, design and test the materials for their performance (including load bearing strength) to meet safe construction standards prior to mass application.</td><td rowspan="5">Overcome negative perceptions, e.g., renovation and innovative use of traditional building materials and design are for the poor.

Re-educate and build capacity for local architects, engineers, builders and skilled technicians.

Initiate quality demonstration projects.

Foster collaboration between NGOs, government agencies and local communities.</td><td>Low-cost to no-additional cost for implementation.</td><td rowspan="5">Environmentally relevant and economically beneficial to rural residents of developing countries, especially least developed countries.

Appropriate to local climate conditions.

Using locally available and accessible resources.

Nurturing local manufacturers.

Creating jobs for local workforces with readily available skills.

Resulting buildings that are contextually, socially and culturally familiar to the local users.</td></tr>
<tr><td>Traditional Chinese practices of building orientation and interior space organisation</td><td>Mainly in China, and other applicable areas in Northern hemisphere.</td><td rowspan="2">Understand the logic behind the relevant principles of traditional Chinese practices of building orientation and interior space organisation for application that improve environmental performance benefits scientifically.</td><td rowspan="2">No-additional cost for implementation.</td></tr>
<tr><td>Traditional building design strategies in the Mediterranean</td><td>Mainly in Mediterranean region, and other hot and arid coastal areas.</td></tr>
<tr><td>Water cool building envelope</td><td>Hot and arid regions.</td><td>Require good technical knowledge and skill for water-proofing construction.</td><td rowspan="2">Require financial arrangements for construction cost and maintenance.</td></tr>
<tr><td>Wind tower</td><td>Hot and arid regions.</td><td>Require maintenance to keep water jar clean, refill water and prevent birds nesting.</td></tr>
</table>

<table>
<tr><th colspan="6">Passive house design and technologies</th></tr>
<tr><th>Associated technologies and practices</th><th>Contextual applicability</th><th>Critical application requirements</th><th>Feasibility for implementation</th><th>Financial requirements</th><th>Contribution to triple bottom line</th></tr>
<tr><td>Passive solar building design</td><td>All regions.</td><td>Design building responding to local climatic conditions, including but not limited to:
– Orientation that is optimised for land form, sun path and seasonal and diurnal prevailing winds
– Self shading design
– Compact form.</td><td rowspan="4">Carry out research to identify appropriate design strategies, quantitative standards and construction details and systems to address local climatic conditions.

Form general design guidelines and standards to serve as springboard for large-scale adoption.

Build capacity for local architects, engineers, builders and technicians.

Organise training workshops for builders and skilled technicians to meet demanding skills, especial in airtight construction and high-performance envelope insulation.

Extend capacity building and supportive institutional setting to local manufacturers, in order for them to produce passive house components and materials locally.</td><td>No additional cost for implementation.</td><td rowspan="4">Saving energy thanks to design optimisation for daylight and ventilation.

Offering building occupants thermal comfort.

Energy saving, resulting in avoiding additional energy demands that lead to additional investment to increase the capacity of local communal power infrastructure and power plants.

Helping local construction workforce to upgrade technical skills, leading to better employment prospects.</td></tr>
<tr><td>Airtight construction</td><td rowspan="2">Temperate regions.</td><td>Require excellent construction skills that pay great attention to details, especially at joints, edge of doors, etc.

Put in place indoor air quality measures, e.g., use low/no volatile organic compound building materials, proper flush-out procedure prior to occupancy.</td><td rowspan="3">Additional investment costs are required for delivering high-performance envelope insulation, triple glazing windows, airtight construction, heat-recovery ventilators, stringent construction details, etc.</td></tr>
<tr><td>High-performance envelope insulation</td><td>Insulate building envelope to stringent standards in order to limit thermal loss.
Install triple glazing system for windows.
Prevent thermal bridge through weak thermal insulation points, such as window frames and joints.</td></tr>
<tr><td>Ventilation with heat recovery</td><td>All regions.</td><td>Transfer thermal energy from discharged air to incoming fresh air to make the temperature of incoming air closer to that of indoor air.</td></tr>
</table>

Lifecycle and integrated design process					
Associated technologies and practices	**Contextual applicability**	**Critical application requirements**	**Feasibility for implementation**	**Financial requirements**	**Contribution to triple bottom line**
Inter-disciplinary and interactive approach	All regions.	Support from committed clients/developers / building owners. Form inter-disciplinary team, comprising client, architect, structural and civil engineer, mechanical and electrical engineer, quantity surveyor, energy consultant, landscape architect, facility manager, contractor (builder) and design facilitator, at the project's inception. Set high performance goals, lifecycle considerations and design targets as the ultimate objectives to direct the interaction and working relationship among the team members. Allow for iterative activity loops throughout each design stage – from conceptual to schematic to detailed design and documentation for construction.	Incentives from government, e.g., taking the lead by being supportive clients for publicly funded building projects. Changing mindset of main players in the building sector to adopt the practice with open mind and a spirit of teamwork. Capacity building to raise awareness among the building sector's players and professionals. Demonstration projects as showcase of process to the industry.	Minimal additional cost is required during building design stage. Additional consultancy cost is required at the project's early design stage. This additional cost will be offset by savings created during the project's construction and/or operational stage.	Providing methodologies and computational tools to deliver high performance buildings.. Addressing the scarcity of natural resources by effectively using building materials and components, and end-of-life considerations. Reducing overall lifecycle costs and social and environmental costs from building design, construction, operation and end-of-life use. Strengthening the relationships among the building-related professionals by promoting teamwork and positive interaction. Providing a platform for cross-learning, knowledge sharing and innovation/ creativity in delivering sustainable built environment.
Lifecycle based decision making		Make design decision based on lifecycle analysis, which takes into account building systems' embodied energy, performances, lifecycle cost, lifespan, end-of-life usage, etc.	Collection of lifecycle information of building materials, products, components, technological systems. Establish comprehensive data bank for lifecycle analysis through collaborations among local building regulators, research institutes, universities, building product suppliers and other building-related professionals.		
Computer assisted design tools		Use computational simulation programmes as tools to assist design for decision making rather than just to verify design intention.	Training local workforce of energy specialists, experts on lifecycle analysis, and experts on computational simulation tools.		

Building envelope thermal insulation					
Associated technologies and practices	**Contextual applicability**	**Critical application requirements**	**Feasibility for implementation**	**Financial requirements**	**Contribution to triple bottom line**
Mineral fibre insulation	All regions.	Be flexible for off-site and in-situ construction. Require good workmanship and foil backing to prevent the product from being exposed to vapour and water. Require good workmanship to prevent air leakage.	Availability of incentive and supporting policies. Enforcement by building codes that safeguard minimum acceptable insulation levels for building envelope. Avoid using cellular plaster insulation products that are associated with the use of ozone depleting agents in its production. Capacity building and training workshops for local professional and construction workforce.	Initial capital costs are required for the products and their installation. No maintenance cost is required for cellular plastic products. Replacement cost is required for mineral fibre and plant/animal derived insulation products. Insignificant cost for application of straw bales and air-gap in cavity wall.	Providing thermal comfort to building occupants. Contributing to healthy living environment and better productivity at workspaces. Reducing energy demands for cooling and heating. Creating business opportunities and jobs.
Cellular plastic insulation		Availability in form of rigid sheet or spray foam. Spray foam to be applied after electricity and plumbing services are installed, so all gaps are properly sealed.			
Plant/animal derived insulation		Require good workmanship and proper backing to prevent the products from exposing to vapour and water. Require good workmanship to prevent air leakage.			
Phase change materials (PCM)		Encapsulate PCM with paraffin, and mix with mortar for application on building environment.			
Use of raw natural elements as thermal insulation, e.g., straw bales, airgap in cavity wall, etc.		Overcome fire-hazardous or combustible materials (e.g., straw bales) by cladding them with metal sheets.			

High performance building façade systems					
Associated technologies and practices	**Contextual applicability**	**Critical application requirements**	**Feasibility for implementation**	**Financial requirements**	**Contribution to triple bottom line**
High-performance solid wall system	Large range of products to meet various climatic contexts.	Design high wall-to-window ratio on west façade. Avoid low wall-to-window for buildings in hot climatic regions. Integrate sun-shading devices for glazing areas exposed to sunlight. Provide airtight but operable windows. Carry out building envelope commissioning.	Incentive and enforcement by building codes that safeguard minimum standards for thermal and daylight performances of building façade systems. Availability of demonstration projects. R&D to determine material availability and types of façade systems that are appropriate to the local climatic conditions. Capacity building to upgrade local professionals' knowledge and to train a workforce with skills for designing, installing, operating and maintaining high performance building façade systems.	Various financial requirements depending on the choice of façade systems. Cost of solid wall systems islower than that of glazing systems (in most cases). Set appropriate window to wall ratio as a cost-effective measure.	Contributing to lower heat gain and/or loss and thus reduce the cooling and/or heating loads of a building. Improving thermal comfort, and offering daylight and visual connectivity to external view for occupants.
Cool paints	Hot climatic regions.				
Glazing systems, including **– Low-emissivity glass** **– Double glazing and triple glazing filled with inert gas dry air, argon or krypton, or vacuum** **– Photochromic glass** **– Electrified glazing**	Large range of products to meet various climatic contexts.				
Double skin façade system	More effective for temperate regions. Less effective in hot climatic regions.	Facilitate nighttime ventilation for application in hot climatic regions.			
Self-cleaning façade solution (TiO_2)	All regions.	Apply to most building façade materials/systems.		Upfront investment to apply TiO_2 coating on the external surface of façade systems will reduce maintenance and cleaning cost during operation stage.	Reducing water consumption for façade cleaning and maintenance costs.

Daylight harnessing technologies					
Associated technologies and practices	**Contextual applicability**	**Critical application requirements**	**Feasibility for implementation**	**Financial requirements**	**Contribution to triple bottom line**
Light shelves (static and movable controlled mechanically or by sensors)	All regions.	Place on upper parts of windows/glazing systems above eye level. Design to allow diffused daylight, not sunlight, entering the building's interior. Apply in building interior spaces, which have more tolerance of some degree of fluctuation in illumination. Deploy in tandem with artificial lighting (controlled by lighting sensors) for more constant indoor lighting levels for office spaces or working/ learning areas. Avoid creating glare for neighbouring buildings. Utilise computational simulation tools.	Put in place relevant regulations to address: Adequate spacing between buildings in according to building height. Safety in relation to installation. Preventing glare and direct reflection to the neighbouring buildings. Availability of guidelines on daylighting design and methodology for daylighting computation. R&D to create a databank of local solar illumination, and suitable technologies suitable to local application. Capacity building in the areas of design and analysis tools for designers, installation techniques for local workforce, and maintenance procedures for building owners and facility management personnel.	Require upfront capital costs for products and their installation. These costs vary according to the technologies, design configurations, types of materials, etc. External static light shelves can be considered as the most cost competitive technology, due to the simplicity of the technology and their combined use as sun shading devices. Require maintenance costs, i.e., cleaning to maintain the optimised performance level. Additional costs should also be set aside for component replacement of mechanical/ sensor-controlled light shelves and skylights.	Contributing to energy saving by reducing artificial lighting requirements and heat generated from artificial lighting. Creating positive psychological impacts for occupants by connecting them with dynamic outdoor illumination.
Sky lights	Mainly temperate regions.	Design to mitigate the problems of rainwater leakage, noise caused by rain, and heat gain/loss. Shade the skylights with other components of the same building, to cut down heat gain, in hot climatic regions. Apply to buildings' interior spaces, which have a higher tolerance of fluctuations in illumination. Utilise computational simulation tools.			
Light pipes	All regions.	Apply in building interior spaces, which have a higher tolerance of fluctuations in illumination. Deploy in tandem with artificial lighting (controlled by lighting sensors) to achieve the constant indoor lighting levels required in office spaces or working/learning areas.			

<table>
<tr><th colspan="6">Highly efficient heating, ventilation & air conditioning systems</th></tr>
<tr><th>Associated technologies and practices</th><th>Contextual applicability</th><th>Critical application requirements</th><th>Feasibility for implementation</th><th>Financial requirements</th><th>Contribution to triple bottom line</th></tr>
<tr><td>Heating systems (boilers, heat pump technologies)</td><td>Temperate regions.</td><td rowspan="3">Require efforts during design stage for coordination, selection and design to result in highly energy efficient HVAC.

Avoid oversizing HVAC components, leading to in-efficient system.

Plan for expansion rather than size it.

Divide building spaces/ rooms into zones, each equipped with their own thermostat, motorised damper and control system for zones and user controllability.

Locate fresh air intake away from air exhausts, (potential) sources of pollution and odour.

Shift peak load in cooling systems to utilise off-peak electricity.

Use displacement ventilation to harness the natural buoyancy of warm air.</td><td rowspan="3">Set minimal performance in building codes for design and implementation of more efficient HVAC systems.

Raise awareness to prevent oversizing HVAC systems through demonstration projects with proven records of energy saving and thermal comfort performances.

Capacity building and training workshop to upgrade professional knowledge and skills.</td><td rowspan="3">Additional investment costs can be minimal by not oversizing HVAC system at the early design stage.

Additional costs are required for additional HVAC subsystems to enhance performance. Examples are the installation of automatic condenser tube cleaning systems, ice storage systems for shifting peak load application, etc.

Additional costs are often recouped from energy saving and reduced maintenance costs.</td><td rowspan="3">Contributing to economic and environmental development through energy saving.

Being catalyst for ESCO businesses to prosper.

Contributing to better indoor living and working environment.

Reducing sick building syndrome and indirectly enhance productivity.</td></tr>
<tr><td>Cooling systems (chillers, condensers, heat exchanger, desiccant wheels, automatic condenser tube cleaning systems)</td><td>Hot climatic regions.</td></tr>
<tr><td>Ventilation systems (variable air volume system)</td><td>Various technologies applicable for various regions.</td></tr>
</table>

EFFICIENT LIGHTING SYSTEMS					
Associated technologies and practices	**Contextual applicability**	**Critical application requirements**	**Feasibility for implementation**	**Financial requirements**	**Contribution to triple bottom line**
Energy efficient lamps (T5/ T8 tubes, compact fluorescent lamps, high-intensity discharge lamps, light emitting diodes) **Ballasts** **Light fixtures**	All regions.	Use efficient lighting systems in association with natural daylight, further enhanced by using lighting sensors. Divide building spaces/room into zones requiring different lighting needs, which can then be independently controlled. Allow users to control the lighting requirement. Install motion sensors to automatically switch the light off, when there is no one in a zone. Install a duel lighting circuit system to allow alternate lights to be turned off at places and times, when having a brightly lit environment is not critical. Provide safe disposal of CFLs at the end of their life, in order to safely dispose of mercury contained in the lamps.	Reduce import tariffs on energy efficient lighting components. Initiating energy efficient lighting programmes, which provide or subsidise energy efficient lighting. Decisions can be made by individual building owners/ occupants. One-time small investment costs can be paid back through savings from electricity bills. Assist local manufacturers to make energy efficient lighting components and systems. Provide public education and campaign to raise awareness.	Initial investment required to purchase and install energy efficient lighting systems. Costs are normally paid back in a short time, e.g., approximately a year, through savings from electricity bills. Maintenance costs are negligible during the lifespan of energy efficient lamps and ballasts.	Contributing to economic and environmental development through saving energy. Consuming fewer resources, thanks to long lifespan. Improving health and living conditions for occupants. Creating business and employment opportunities, once local manufacturers can meet local demand.

<table>
<tr><th colspan="6">Water efficiency technologies</th></tr>
<tr><th>Associated technologies and practices</th><th>Contextual applicability</th><th>Critical application requirements</th><th>Feasibility for implementation</th><th>Financial requirements</th><th>Contributions to triple bottom line</th></tr>
<tr><td>Metering and water consumption information</td><td rowspan="5">All regions.</td><td>Install meters at locations that are easy to access for reading.
Protect meters from the weather.
Install separate sub-meters for different units, or major uses (e.g., landscape irrigation, cooling tower, etc.) in large-scale buildings.
Link data from all sub-meters to the building management system.</td><td>Availability of regulations on water metering.
Demonstration projects with proven data related to water saving for complex metering systems in large-scale buildings.</td><td rowspan="5">Various systems require different initial investments, which in general, are low.
Return on investment varies in according to specific systems adopted and the contexts. For example, ROIs for complex rainwater harvesting systems on high-rise buildings in a high-density urban setting are not as attractive as those for simple roof-gutter-tank systems of smaller buildings in rural settings.
A budget should be set aside for maintenance, e.g., cleaning, repairing the systems, and replacing components.</td><td>Contributing to the environment through conserving water resources and indirectly reducing energy consumption.
Ability to detect water leaks.</td></tr>
<tr><td>Rainwater harvesting systems</td><td>Use non-corroding materials for components.
Size storage tank based on roof catchment area and local rainfall data.
Use collected rainwater for non-potable usage.
Regular clean up of contaminants, dry leaves, etc.</td><td rowspan="2">Availability of guidelines for design and installations of rainwater harvesting system.
Availability of guidelines for preliminary water treatment and/or water purification for drinking (applicable for regions with scarce water resources and limited communal water supply.)
Availability of guidelines and regulations related to environmental health – i.e., prevention of mosquito breeding in rainwater/grey water storage tanks/ containers.</td><td>Reducing the stress on the municipal storm water system.
Reducing surface storm water runoff and cutting down peak discharge to urban drainage systems.</td></tr>
<tr><td>Grey water re-use systems</td><td>Separate grey water and black water piping systems.
Disinfect the stored water to prevent cross contamination and growing of bacteria/fungi.
Use the stored grey water as soon as possible.
Require regular maintenance and check for leakage, replace treatment medium and prevent mosquito breeding and bacteria growth.</td><td rowspan="3">Engaging end users to conserve water, and instilling positive environmental-friendly habits and practices to the society at large.</td></tr>
<tr><td>Hydro-pneumatic water supply systems</td><td>Require space on high level (roof) for the air-pressured water tank.
Require sensor to monitor water level and pressure in the tank. Link the data to central building management system.</td><td>Capacity building to establish a pool of local skilled technicians/trades to design, install and maintain the systems.</td></tr>
<tr><td>Water-saving devices (aeration technologies, dual flushing water closet, water-saving dishwashers, clothes washers, drip irrigation systems)</td><td>Add aerators to existing water taps or shower heads.
Specify and equip buildings with dual-flush toilets and water-saving appliances.
Programme drip irrigation systems to fit local weather requirements.
Identify opportunities for zones (of plants with different water needs) for zone controls.</td><td>Raising awareness to buildings occupants, professionals, builders and public at large, by local governments and/ or NGOs.
Introducing labelling system for water-saving devices.</td></tr>
</table>

<table>
<tr><th colspan="6">Carbon-sequestration and low-carbon building materials and products</th></tr>
<tr><th>Associated technologies and practices</th><th>Contextual applicability</th><th>Critical application requirements</th><th>Feasibility for implementation</th><th>Financial requirements</th><th>Contributions to triple bottom line</th></tr>
<tr><td>Carbon sink building materials and products (harvested wood products, bamboo products)</td><td rowspan="2">All regions.</td><td>Enhance the products with lamination and/ or chemical treatment to reduce vulnerability to termite infestation, and to strengthen their water- and humidity-resistance.</td><td rowspan="2">Raising awareness through public educational campaigns.

Establishing green labelling/carbon labelling schemes by government agencies or reputable NGOs.

R&D to identify and develop new materials and products and their innovative applications.</td><td rowspan="2">No additional investment is required, as the materials and products are substituted to the otherwise conventional carbon-intensive ones.

Savings from reducing transportation costs, by using locally available materials.</td><td rowspan="2">Substituting conventional carbon intensive materials and reducing demand for them in the market.

Promoting the use of locally available materials, and thus supporting local industries for employment opportunities and economic growth.</td></tr>
<tr><td>Low carbon building materials and products (low-carbon bricks, green concrete, green tiles, recycled metals, locally available materials and products)</td><td>Reduce or avoid wastage during process and application.</td></tr>
</table>

<table>
<tr><th colspan="6">Greening and building integrated greenery systems</th></tr>
<tr><th>Associated technologies and practices</th><th>Contextual applicability</th><th>Critical application requirements</th><th>Feasibility for implementation</th><th>Financial requirements</th><th>Contribution to triple bottom line</th></tr>
<tr><td>Garden and landscape</td><td>All regions.</td><td>Maximise soft-scape where land is available.</td><td rowspan="4">Incentives from local government, such as cost sharing schemes.

Capacity building, especially in the following areas:
– Planning, designing skills and plants selection.
– Installation technique, including water proofing and irrigation systems.
– Maintenance procedures for building's owners and facility management personnel.
– Manufacturing and supplying lightweight components.</td><td>No additional cost required, because it is a common practice.</td><td rowspan="4">Reducing heat gains for buildings in hot climatic regions.

Reducing heat island effect in urbanised areas.

Absorbing airborne particles and improving ambient air quality in urban settings.

Nurturing and enhancing urban biodiversity.

Reducing rainwater and peak rainwater run-off.

Absorbing carbon dioxide for photosynthesis.

Creating biophilic value to building occupants and city dwellers.

Providing alternative public spaces for leisure activities and fostering community ties in high-rise high-density urban setting.

Reducing building cooling load, leading to lower energy consumption and thus cost savings to owners/tenants.

Enhancing the buildings' marketability and value.

Reducing the diurnal temperature fluctuation of the building roofs and facades, leading to reduction in materials' contraction and expansion, and thus prolonging the building roofs and facades' lifespan.

Nurturing the prosperity of new supply chains and new job creation.</td></tr>
<tr><td>Green roofs</td><td rowspan="3">All regions, excluding extreme temperate regions, or hot and arid climatic regions.

More suitable in densely populated urban areas.</td><td rowspan="3">Design building structure to support additional dead loads.

Provide good water proofing system and measures to prevent structural damages caused by root penetration or water leakage.

Deter the risk of plants or tree branches falling from the buildings.

Design, install and maintain irrigation, water storage and drainage systems appropriate to local climatic conditions.

Select lightweight substrate and media for plants to grow on.</td><td rowspan="3">Additional initial investment cost for the products, their installation and stronger structural elements. These costs vary from system to system and from region to region.

Ongoing maintenance costs are required.</td></tr>
<tr><td>Roof gardens, balcony gardens and sky terraces</td></tr>
<tr><td>Green façades/ walls</td></tr>
</table>

<table>
<tr><th colspan="6">Solar technologies</th></tr>
<tr><th>Associated technologies and practices</th><th>Contextual applicability</th><th>Critical application requirements</th><th>Feasibility for implementation</th><th>Financial requirements</th><th>Contribution to triple bottom line</th></tr>
<tr><td>Solar thermal water heater</td><td>Most temperate and hot climatic regions.</td><td rowspan="3">Design building structure and roof to cater for additional dead load of the system.

Design for accessibility for maintenance and services.

Require stability and sufficient pressure of continuous water supply for automatic operation of solar thermal water heaters.</td><td rowspan="6">Require strong institutional supports, especially incentivising policies and supportive financial mechanism, including:
– Reducing/removing subsidies for fossil-fuel-based electricity supply.
– Reducing/removing import tariffs on solar technologies' components.
– Clearly identifying power grid expansion plans (for rural and remote areas) and communicating these plans to the public. This is necessary for calculating payback periods used in decision-making processes to invest and implement off-grid solar technologies, e.g., Solar home systems and solar charging stations.
– Setting up smart grids and incentivising feed-in tariffs as a platform to promote on-grid application of PV technologies.

R&D in priority areas, including:
– Local data of solar radiation, intensity and sunlight hours for various seasons.
– Locally most suitable, efficient and cost effective solar technologies and products for large-scale development.
– Viable business models and financial mechanisms for a reasonable return on investment.
– Capacity building in the area of technical knowledge, design techniques for professionals, installation skills for technicians, and routine inspection and maintenance for building owners and facility management personnel.</td><td rowspan="6">Requirement of investment costs of the products and their installation, and maintenance costs.

PV technologies require more capital intensive to invest, compared to solar thermal technologies.

The costs of components vary, depending on the technologies and wither the products are produced locally or imported.</td><td rowspan="6">Seen as prominent and promising technologies to substitute fossil fuel based electricity.

Contributing to improve quality of life and deliver healthy environment.

Bring direct benefits to home owners and communities (in remote rural setting).

Creating business opportunities for remote rural community with solar charging systems.</td></tr>
<tr><td>Combining solar water heating and space heating (combi-system)</td><td>Temperate regions.</td></tr>
<tr><td>Combining solar heating and solar cooling system</td><td>Hot climatic regions.</td></tr>
<tr><td>Building integrated photovoltaic (bipv)</td><td>All regions.</td><td rowspan="3">Located PV panels exposed directly to sunlight.

Mount PV panels to face the sun directly.

Require periodic maintenance to clean the surface from accumulated dust and/or bird droppings, etc.)</td></tr>
<tr><td>Solar home system</td><td rowspan="2">Remote rural areas of all climatic regions.</td></tr>
<tr><td>Solar charging station</td></tr>
</table>

Building integrated wind turbines					
Associated technologies and practices	**Contextual applicability**	**Critical application requirements**	**Feasibility for implementation**	**Financial requirements**	**Contribution to triple bottom line**
Horizontal axis wind turbines (HAWTs)	All regions, especially windy coastal areas.	Collect wind data in the immediate vicinity of the building or installation site. Determine suitable wind turbine types and installation locations, in order to maximise the potential energy generated from the turbines, by matching ambient wind conditions with a wind turbine's cut-in wind speed, rated wind speed and cut-out wind speed. Ensure building's structure is strong enough to withhold the additional dead loads and vibration loads from the turbine's operation. Adopt vibration absorbent technology to prevent damage to building structure and to minimise noise penetrating the building's interior. Put in place measures to deter wind turbines from being damaged by lightning. Plan for accessibility for maintenance and services. Applicable to both grid-connected or off-grid settings.	Building up local wind mapping to understand wind speed, frequency and directions at different heights, times, and settings. Putting in place supporting policies and financial mechanisms to make building integrated wind turbines commercially viable: – Reducing or removing subsidies for fossil fuel based electricity supply. – Reducing or removing import tariffs on wind turbine components. – Clearly identifying power grid expansion plans (for rural and remote areas) and communicating these plans to the public. – Setting up smart grids and incentivising feed-in tariffs as a platform to promote on-grid application of building integrated wind turbine technologies. Setting guidelines and standards to regulate the installation, to address: – Structural safety – Noise pollution control – Grid connection – Urban-scape design guidelines. Capacity building: – Technical knowledge to compute, simulate and select appropriate types of wind turbines at appropriate locations. – Installation skills and techniques for local workforce. – Maintenance procedures for building owners and facility management personnel. – Manufacture of micro wind turbines and related components, for long-term development.	Initial investment costs for feasibility studies and system design, the wind turbines, their installation, and additional strength of building structure. The cost components of wind building integrated wind turbine system vary widely, depending on the types, capacity rating and local availability. Maintenance budget to be set aside for parts' replacement.	Contributing to reduce the need for fossil-fuel-based electricity. Opportunities for building owners to sell surplus electricity back to the grid. Providing local workforce new skills and employment opportunities. A mechanism for local green economy to prosper. Wind home systems contribute to social development by improving the quality of life to villagers in remote islands and rural areas.
Vertical axis wind turbines (VAWTs)					
Wind home systems (WHSs)					

Energy management and performance improvement					
Associated technologies and practices	**Contextual applicability**	**Critical application requirements**	**Feasibility for implementation**	**Financial requirements**	**Contribution to triple bottom line**
Commissioning	All climatic regions. Most suitable for commercial buildings and large-scale mix-use complexes.	Verifying performance against the targets set at the early stage of building design, ensuring that installations undergo onsite inspection, and that all technical systems tested and faults rectified. Engaging an independent commissioning agent during handover of complex and large-scale buildings to help eliminate hidden deficiencies. Providing building user guide, to explain the operational procedures and functions of complex technical systems.	Agreement between building developers and builders/ contractors. Providing institutional supports, such as legal requirements to mandate commissioning on contracts of certain complex building types. Commissioning of advanced technologies/ systems requires training operating/ facility management staff and educating potential users.	Building developer to invest a one-time cost for building commissioning	Ensuring good performance of technical systems, and improving their life cycle performances. Enhancing environmental health and comfort level. Reducing training and familiarisation costs for facility management staff. Saving from utility bills, and improving productivity.
Building Energy Management System (BEMS)		Most beneficial when considered and incorporated during building design stage. Require skilled personnel to operate and monitor the data from BEMS. Put in place user interface and manual-override functions for possible intervention in case of system breakdown and/or emergency situations.	Capacity building to train highly-skilled technicians to install and operate the system.	Require additional cost for installing, operating and maintaining the system.	Optimising energy usage to create energy savings. Offering early warning and detection of problems, and ease of problem diagnostics.
Energy Performance Contracting (EPC)		Require strong support from building owners. ESCOs to define clear baselines – existing energy consumption, patterns and rates, equipment inventory, occupancy, existing energy saving measures, etc.– based on spot measurement, metering, inspections and surveys. Devise technological interventions, measured against baselines for calculating potential savings from energy consumption in monetary terms and the payback period. Setting up project specific measurements and verification plan, maintenance schedule, expenses and payback. Carrying out post-installation verification, periodic performance verification, operational feedback and fine-tuning.	Availability of institutional supports, including: – Non-subsidised electricity price. – The availability of feed-in tariff. – Financial assistance from international and local organisations at the initial start-up phases.	Building owners are not expected to any additional investment cost for EPC, except for experiencing some disruptions during installing intervention technologies by ESCOs.	Providing opportunities to improve energy performance of large existing buildings. Providing opportunities for existing buildings' owners to upgrade old equipment and systems. Being a small-scale green financing mechanism that unlocks the financial bottleneck of large-scale implementation of energy-efficient and renewable energy technologies.

Behaviour change catalysts					
Associated technologies and practices	Contextual applicability	Critical application requirements	Feasibility for implementation	Financial requirements	Contribution to triple bottom line
Energy efficient appliances	All regions and contexts.	Requiring no special spatial or additional technical requirements for application, as the products are typically no different in terms of size and shape, compared to the conventional ones.	Availability of institutional supports, such as product energy labelling schemes.	Energy efficient appliances, in general, cost more than conventional ones. However, the additional cost can be recouped through energy savings during operation.	Contributing directly to domestic energy savings. Being a catalyst for behaviour change toward a more sustainable lifestyle. Contribution towards implementing dynamic pricing of electricity, which in turn helps reduce peak demand, to alleviate energy shortages and the need for power infrastructure expansion.
Home area network (HAN)	For domestic application in all regions.	Connect electrical domestic appliances and systems (e.g., HVAC, lighting, refrigerators, washing machines, water heaters, televisions, computers, etc.) to smart meters.	Requiring more R&D and test bedding. Establishing a common set of standards and protocols for compatible integration of various HAN products and fine tuning them to be more user-friendly and appealing to end-users. Setting up demonstration projects, showrooms to raise awareness at the initial market penetration stage. Further R&D to bring down the cost. Availability of a simple form of electricity dynamic pricing.	Initial investment to purchase and install the related equipment. Additional operational cost to the energy used in the in-home display unit, and system/software upgrade.	
Pre-paid meters	Most suitable for least developing countries	Require the credit and/or vending system set out by utility providers. Protect meters from the weather, especially rain. Locate meter away from potential contact with water or heat sources Position meter so it can be easily used and maintained.	Good collaboration and communication between power plant operators, utility providers, local government and local community. Online vending systems can only be implemented in communities where majority of households have access to internet.	Financial investment from a utility provider to lay the distribution infrastructure, install vending machines, and operate the system. Small upfront investment is often required for the consumers to purchase and install pre-paid meters in the homes.	

<table>
<tr><th colspan="6">Community based energy services</th></tr>
<tr><th>Associated technologies and practices</th><th>Contextual applicability</th><th>Critical application requirements</th><th>Feasibility for implementation</th><th>Financial requirements</th><th>Contribution to triple bottom line</th></tr>
<tr><td>District heating/ cooling</td><td>All regions, and more feasible in high-density urban setting.</td><td rowspan="2">Set up centralised plants to produce heating/ cooling through boilers/ chillers, recover waste heat through co-generator, or tap into waste heat from nearby industrial processes or power plants.

Deploy renewable and clean energy sources (where possible) for thermal energy conversion.

Utilise heating-cooling conversion technologies to address the different thermal requirements of a year.

Setting distribution network of thermally insulated metal pipes and pumps to transfer thermal energy from the centralised plant to individual buildings within a community.

Put in place leak detection systems and corrosion protections for underground piping.

Use variable speed pumps with low noise generated to save pumping energy and prevent noise transfer through the thermal medium into the buildings.

Install in individual buildings: heat exchanger, piping, valves and control system, e.g., thermostats, and meter.

Require periodic maintenance, including leakage inspection, monitoring and reporting the system's performance.</td><td rowspan="2">Setting up suitable investment and financing mechanisms.

R&D to identify energy sources, suitable system, technologies, and system capacity to serve the communities.

Conducting user consultation to gain common understanding, expectations and cooperation, during feasibility study, design, construction, and operation stages.

Capacity building to train local workforce with technical skills to install, monitor, identify faults, and repair the systems.</td><td rowspan="2">Require investor and master developer to invest initial capital to set up the systems, operational cost and maintenance cost.</td><td>Being more thermally efficient in densely urban setting, compared to that of many isolated small systems in individual buildings.

Optimising the operation of the centralised plant in terms of energy efficiency, renewable energy deployment and maintenance personnel.</td></tr>
<tr><td>Combined heat and power generation (CHP)</td><td>All regions, and more feasible in rural lower-density setting, where accessibility to renewable and alternative energy sources area easy.</td><td>Efficient in electricity generation with the use of the byproduct – i.e., heat.

Creating opportunity to tap renewable or cleaner energy sources.

The combination of a biogas anaerobic digester and a CHP co-generator offers better sanitation solutions for rural communities, reducing odour and flies, preventing water pollution due to waste dumping, and improved environmental health.

Creating sense of community and strengthen social coherence within a community.

Offering buildings' owners:
– Savings on capital cost for installing boiler/ chiller plants, and thus saving on building spaces.
– Savings on ongoing capital expenses to upgrade boiler/chiller plants.
– Flexibility, monitoring ability and controllability of thermal energy usage.</td></tr>
</table>

<table>
<tr><th colspan="6">Sustainable community design and practices</th></tr>
<tr><th>Associated technologies and practices</th><th>Contextual applicability</th><th>Critical application requirements</th><th>Feasibility for implementation</th><th>Financial requirements</th><th>Contribution to triple bottom line</th></tr>
<tr><td>Sustainable community design and physical planning</td><td rowspan="2">Various planning and practices strategies applicable to various contexts of communities</td><td>Planning buildings layout of a community responding to local sun and seasonal wind characteristics, harvesting rainwater and enhancing local landscape ecology.</td><td rowspan="2">Involving as many stakeholders to appraise the status of existing conditions.

Designating individual(s) as champion for sustainable community programmes.

Identifying, together with stakeholders, key needs and objectives, through consensus building.

Creating vision and workable roadmap.

Developing a set of indicators to benchmark and monitor the progress.

Identifying and communicating with supporting partners.

Starting with the most feasible and economical activities.

Monitoring and improving the activities as progressing.

Continuing seeking feedback from all stakeholders and partners.</td><td rowspan="2">Financial support is required at the initial stage for a kick-off, usually related to planning and early stage implementing activities.

Low-income communities often require financial support by international agencies and/or local government.

Successful community activities often find themselves a sustainable income stream generated from the return on investment.</td><td>Planning with regard to local climatic conditions, including sun, wind and rain.

Creating comfortable micro-climate for both communal spaces and individual buildings in a community.

Being water efficient.

Promoting native vegetation, and nurturing biodiversity.</td></tr>
<tr><td>Sustainable community practices (building a sense of community, upgrading quality of life, developing skill sets gearing towards green economy)</td><td>Discuss with members of the community to understand existing lifestyles, daily activity patterns, and their wish list for improving the living experience in the community.

Encourage all members of the community to participate in all communal activities.

Empower members in all decision-making processes and instill a sense of ownership and pride.</td><td>Reducing and eliminating poverty for lower-income communities, while upgrading their skills for employability in green economy sector.

Facilitating a sustainable local green economy, e.g., through eco-tourism, local food production, etc.

Generating community ties and sense of ownership.

Reducing crime.

Improving quality of life.</td></tr>
</table>

Appendix II: Glossary

Building Energy Management System: is a computer based control system installed in buildings. BEMS integrates the monitor and control of mechanical and electrical systems within a building into an overall control and optimisation strategy related to energy and occupant comfort.

Building integrated greenery system: allows the integration of greenery on to a building itself and even becoming part of building components (such as green roof and green wall).

Building integrated photovoltaic: consists of Photovoltaic panels, which are integrated into roofs, façades, skylights or sun-shading devices of buildings.

Building integrated wind turbines: are micro wind turbines, which are integrated into building rooftop to convert energy of air movement to electricity.

Carbon sequestration: a building can act as a carbon sink, either statically through the use of carbon-trapped building materials, or progressively through the integration of greenery on the buildings and within the building site.

Carbon sequestration building materials: are mainly sourced from harvested wood products (HWPs). Wood is harvested from trees which capture carbon through photosynthesis process. 50% of the dry weight of wood is carbon.

Cellular plastic insulation: refers to thermal insulation products that are oil-derived, and include rigid polyurethane, phenlic, expanded polystyrene, and extruded polystyrene.

Chiller: is a component of centralised HVAC system. It produces cool water, which is then pumped to air handling units to cool the air.

Community based energy services: provide heating, cooling and renewable energy to more than one building. They are often found in two forms – district heating/cooling and combined heat and power (CHP) generation.

Compressed earth blocks: a renovated traditional building material found in India, East Africa and South America, compressed earth blocks are made of a semi-dry mix of clay and sand and produced in the modern time through the use of mechanised hydraulically compressed block machine.

Computer assisted design tools: These tools simulate building performances, calculate energy required for cooling or heating, CO_2 emission, life cycle analyses, etc. Simulation tools are particularly useful to make visible design strategies and to predict the building performances, usually in the areas of sun path and sun shadow, daylight, computational fluid dynamic for air movement, etc.

Displacement ventilation: typically supplies conditioned air from raised floor system through a series of adjustable floor-mounted registers. The room air is stratified where lower temperature air stays in the bottom portion of the room (where people are located and cool air is needed) and high temperature air rises towards the ceiling.

District heating/cooling: refers to combined heating/cooling at a centralised location, and distribution of heating/cooling to the buildings of a defined community, through a piping network, for space and water heating or space cooling. The energy required for heating/cooling can be tapped from waste heat from nearby industrial processes (if available) and/or renewable sources such as solar thermal and geothermal energy.

Double skin façade: consists of two glass skins arranged with a ventilated intermediate cavity of 0.2 metre to as wide as 2 metres. For wider cavity – i.e., 0.6 metre or more, perforated metal catwalks are usually installed for cleaning and maintenance accessibility. Sun shading devices, such as operable blinds, can be installed within the ventilated cavity.

Energy efficient lighting system: includes energy efficient lamp, ballast and light fixture. Discharge lamps (such as compact fluorescent lamps, T5 and T8) and electro-luminescent radiators (light emitting diodes) are considered as energy efficient lamps.

Energy Performance Contracting: is a performance-based procurement method and financial mechanism for building renewal, whereby utility bill savings, which result from the installation of new building systems that reduce energy use, pay for the cost of the building renewal project.

Evaporative cooling: is achieved during the evaporative process of water, in which the air temperature drops when the air volume takes up water by transforming it from liquid to vapour forms.

Flush out: is a measure to address indoor air quality. The procedure involves in having the newly completed buildings fully opened for air circulation for a required continuous period before occupancy.

Green roofs: are covered extensively with vegetation, such as grass or shrubs using an integrated support system. This system includes substrate, filter, irrigation, water storage and drainage system as well as water proofing of a roof surface/structure. Green roofs are designed to be lightweight, and typically cannot support heavy public activities, except for maintenance.

Green facades/walls: allow plants to grow on building façade/wall surfaces through various means – creepers with self clinging roots on wall surfaces, twining plants on mesh or cable support, and carrier panels with pre-grown plants fixed vertically on walls (NParks, 2009).

Green Plot Ratio: measures the total leaf area index over a building site using a volumetric approach, taking into consideration of green walls, green roof, sky gardens, etc.

Greenhouse gases (GHG): are gases that trap heat in the atmosphere, principally water vapour, carbon dioxide, methane, nitrous oxide and ozone. The increasing concentrations of GHG are raising the Earth's average temperature and causing a range of other adverse climate and weather effects.

Heat pump: extracts heat sources from warmer underground earth, air or sub-surface water during winter months in temperate region to condition the temperature for indoor usage. Reversing the above cycle during summer months, heat pump extracts heat from indoor to outdoor, in order to provide cooler indoor temperature.

Heating, ventilation and air conditioning (HVAC): is a mechanical system to supply fresh air and condition the indoor air temperature and humidity of a building. The system normally consists of components to supply, filter, heat, cool and distribute the conditioned air into the targeted interior spaces.

Home area network: is a network within a home that connects electrical domestic appliances (i.e., HVAC, lighting, refrigerators, washing machines, water heaters, televisions, computers, etc.) to smart meters. The smart meters allow homeowners/tenants to monitor and manage their energy use.

Hydro-pneumatic water supply systems: introduce air pressure in water tanks as a key energy-saving component in water supply systems for building use. The compressed air in the tank serves three main functions – i.e., supplying water at a preset pressure range, reducing pressure surges in the water supply systems, and using the pressure setting to monitor and control water pump.

In-situ construction: is a construction method that is carried out at the building site using raw materials. In-situ construction is in contrast to prefabricated construction, in which building components are made in a factory and then transported to the building site for assembly.

Integrated design process: is a design process to deliver a building, in which its relationship to surrounding context, technical components and technologies are parts of a whole system and for the whole building life cycle (Larsson, 2005). This objective can be obtained once interdisciplinary professional team members embark and interact on the project right from the inception and conceptual design to jointly make strategic decisions and address all design issues together.

Life cycle (of a building): includes all stages of a building's life. These stages are manufacturing of building materials,transporting building materials from sources / production plants to building sites, constructing the building,operating the building, and demolishing the building,

Light pipe: consists of transparent dome on the external, a reflecting metal pipe and a diffuser to be installed on ceiling. The dome collects and magnified external daylight, which is transmitted through the internal reflective metal pipe to the diffuser, which in turn distributes the defused daylight to the internal space below.

Light shelve: is special designed sun-shading device, placed on the upper part of windows/glazing façade above eye level. While the natural lighting condition under light shelve near the window is saturated and glare is circumvented, defused daylight is reflected on the top of the light shelve to the ceiling area (near the window) and further reflected into the interior spaces.

Low-carbon / zero-emission buildings: achieve their common objective to minimise GHG emissions to the atmosphere by integrating available energy efficient design techniques, strategies and technologies, and/or by using renewable energy for their operations.

Low-carbon building materials: can be sourced from materials with both low embodied energy and carbon in their productions, assembly, and transportation process. Due to such broad-based definition, low-carbon building materials are interpreted differently in different contexts. For example, metal products are considered as high-embodied carbon materials because its extraction and refinement processes are carbon intensive. However, recycled metal products used in new buildings can be considered low-carbon.

Mineral fibre insulation: refers to thermal insulation products that are mineral based. The range of products includes rock wool, slag wool and glass wool. The raw materials are melted at high temperature, spun into fibre and added with binder to form rigid sheets and insulation batts. If removed in appropriate condition, mineral fibre can be reused and recycled at the end of life.

Micro-hydro power: is power produced from tapping on the energy of moving water in streams and small rivers. The power can be used to generate electricity, or to be used in hybrid system of combined heat and power plant.

Mitigation options (from building sector): can be defined as deploying and implementing design strategies, technologies and practices that (a) reduce energy demand and consumption associated with the buildings – from design, construction, hand-over, operation to renovation and end-of-life arrangement, (b) switch to low- or no-carbon fuels, (c) maximise the opportunity for buildings to act as carbon sink, and (d) are catalysts for behaviour change towards sustainable lifestyle.

Overall Thermal Transfer Value (OTTV): is a measure of the energy consumption of a building envelope. Its formulation takes into considerations of important envelope components, such as type of glazing, window size, external shading to windows, wall type and colour.

Passive house: takes the conventional passive solar building design principles as a starting point and combining them with air tight and well insulated building envelope to derive very low energy buildings. Passive house is a building in which a comfortable interior climate can be maintained without active heating and cooling systems. The house heats and cools itself, hence “passive” (Passive House Institute, 2010).

Passive solar design: are design strategies that enable buildings to be well responded to the bio-climatic and geographical conditions of the building site and its immediate surrounding environment. The objectives are to reduce energy demand for thermal comfort, artificial lighting and other building environmental performances. The strategies include site selection, design responsive to the sun,design responsive to wind, and use of thermal mass materials.

Phase change materials (PCM): work based on latent heat storage principle. When temperature rises, the temperature of a latent heat store does not increase but the medium changes from one physical state to another and by this means it stores energy. Therefore the take up of energy cannot be detected by touch. The temperature only rises detectably after a complete change of phase has taken place.

Plant/animal derived insulation: refers to thermal insulation products that are plant or animal derived, and include cellulose fibre, sheep wool, cotton, and flax. These products have low embodied energy, as the materials can be sourced from renewable raw materials. These products are in the form of fibre, batts or compressed board.

Photovoltaic technology: harnesses power from the sun by converting light into electricity through photovoltaic process.

Prepaid meters: are electricity meters that require consumers to pay up-front for a certain amount of electricity prior to consuming it.

Rainwater harvesting system: is a technology facilitating the practice to collect good quality water from natural precipitation. The most popular method to harvest rainwater is collecting through roofs or other building surfaces. A simple system includes roof gutter and downspouts, linking to a storage tank.

Residential and commercial buildings: while the definition of residential buildings is straightforward and includes single house, semi-detached houses, townhouses, apartments; commercial buildings refer to all non-domestic residential buildings, such as public, tertiary, office, municipal, etc.

Roof gardens, balcony gardens and sky terraces: are gardens with plants located on rooftops, balconies and terraces of buildings with accessibility for outdoor activities. Integrated irrigation, drainage and waterproofing are the common components.

Self-cleaning façade solution: is popularly found in the form of titanium dioxide (TiO_2), which can be applied on both solid walls and glazing system. TiO_2 is a type of photo-catalyst. When exposed to sunlight, TiO_2 activates its oxygen molecules to decompose germs, bacteria and organic matters. Therefore, when applying TiO_2 coating on external façade surfaces – i.e., aluminium claddings, wall tiles, glass, etc., the façade performs a self-cleaning function.

Solar thermal technology: harnesses power from the sun and converts it to heat energy.

Stabilised rammed earth foundation: is an innovative application of traditional practices of using earth as building materials. The soil, which is excavated from the trench foundation, is sieved and mixed with cement and sand to become construction materials for building foundation

Stakeholders (of building sector): include but not limits to property developers, financiers, project managers, architects, civil and structure engineers, mechanical and electrical engineers, facility managers, owners, tenants, sub-tenants, etc.

Subsoil heat exchanger: is a process to channel incoming air through ducts buried underground. The constant earth temperature, which is often warmer in the winter and cooler in the summer, helps pre-heat/pre-cool the incoming air.

Sun shading device: keeps direct sunlight from shining on glazing surface, enhances the shading co-efficiency of facades, and results in less thermal transmittance through the façade system.

Sustainable community design and practices: refer to planning, designing, building, managing and promoting social and economic development of communities to meet sustainable development objectives.

Thermal comfort: is a 'condition of mind which expresses satisfaction with the thermal environment' (ISO7330). Such perceptions are affected by air temperature, radiant temperature, relative humidity, air velocity, activity and clothing.

Thermal ice storage: Ice is generated during off-peak hours and stored for chilled water generation use during peak hours, helping reduce electricity peak load.

Thermal insulation: refers to construction materials with low thermal conductivity. They help reduce energy consumption in buildings by preventing heat gain/loss through building envelope.

Thermal mass materials: simply absorb and store warmth and coolness to prevent large changes of indoor temperature as the outdoor temperatures vary in a large range and short timeframe. Masonry, stone products and concrete have good thermal storage capacity.

Value engineering: refers to cost-cutting exercises during the later stage of design development.

Zone control: is a strategy used to derive higher efficient HVAC system or artificial lighting systems. Wherever possible, spaces/rooms in a building should be divided into smaller enclosed rooms and zones each equipped with own thermostat, motorised damper, sensors, switch and control system. In this way, users are able to adjust the room temperature and/or lighting independently to suit their thermal comfort level and/or lighting needs.

Appendix III
Additional Sources of Information on Mitigation Technologies and Practices

Renovation and Innovative Use of Traditional Building Materials & Technology

Preliminary list of research institutes/organisations:

1. Auroville Earth Institute (India): www.earth-auroville.com
2. The Energy and Resources Institute (India): www.teriin.org

Passive House Design and Technologies

Preliminary list of research institutes/organisations:

1. International Passive House Association (International): www.passivehouse-international.org
2. Passi Haus Institute (Germany): www.passiv.de/07_eng/index_e.html
3. PASS-NET (Europe): www.pass-net.net

Preliminary list of technology designers/providers:

1. Arquitecto Eva Ibars Novella (Slovenia): www.ibars.si
2. Projektant Pozemnych Stavieb Katarína Bódiová (Slovakia): http://projekty.bodi.sk

Life Cycle and Integrated Design Process

Preliminary list of research institutes/organisations:

1. International Energy Agency – Task 23(Global): www.iea-shc.org/task23
2. International Initiative for a Sustainable Built Environment (Global): www.iisbe.org

Preliminary list of technology providers:

1. Autodesk (Global): www.autodesk.com
2. Bentley (Global): www.bentley.com
3. Integrated Environmental Solution (Global): www.iesve.com/RestOfWorld

Building Envelope Thermal Insulation

Preliminary list of research institutes/organisations:

1. Laboratory of Heat Transfer and Environmental Engineering, Department of Mechanical Engineering, Aristotle University, Greece. http://www.meng.auth.gr/el.html
2. National Research Council Canada, Institute for Research in Construction: www.nrc-cnrc.gc.ca

Preliminary list of technology providers:

1. Africa Thermal Insulations (South Africa): http://www.alububble.co.za
2. Hangzhou Phase Change Technology Co., Ltd. (China): http://hzfeijie.en.alibaba.com
3. BASF (Asia / Pacific and North America) http://www.basf.com/group/corporate/en/contact

High Performance Building Façade Systems

Preliminary list of research institutes/organisations:

1. Centre for Total Building Performance, National University of Singapore (Singapore): www.ctbp.bdg.nus.edu.sg
2. Division of Energy and Building Design, Lund University (Sweden): www.ebd.lth.se/english
3. Buildings Technology Department, Lawrence Berkeley National Laboratory (US): http://lowenergyfacades.lbl.gov

Preliminary list of technology providers:

1. Somfy for Bioclimatic Facades (Global): www.somfyarchitecture.com
2. Advanced Glazings (Canada): www.advancedglazings.com
3. Viracon (Global): www.viracon.com

Daylight Harnessing Technologies

Preliminary list of research institutes/organisations:

1. Daylighting Collaborative (US): www.daylighting.org/index.php
2. MIT Daylighting Lab (US): http://daylighting.mit.edu/home.php

Preliminary list of technology providers:

1. Solatube International (Global): www.solatube.com

2. Solar Tracking Skylight Inc (USA): www.solar-track.com

Highly Efficient Heating, Ventilation & Air Conditioning Systems

Preliminary list of research institutes/organisations:

1. American Society of Heating, Refrigerating and Air-Conditioning Engineers (USA & Global): www.ashrae.org
2. Energy System Laboratory, Nanyang Technological University (Singapore): www.mae.ntu.edu.sg/AboutMAE/Divisions/ESLab/Pages/Home.aspx

Preliminary list of technology providers:

1. Trane Inc. (Global): www.trane.com/Corporate/default.asp
2. Broad Air Conditioning (China): http://www.broad.com

Efficient Lighting Systems

Preliminary list of research institutes/organisations:

1. en.lighten Initiative (Global): http://www.enlighten-initiative.org
2. Efficient Lighting Initiative (East Asia & Southern Africa): www.efficientlighting.net
3. International Association of Lighting Designers (Global): www.iald.org
4. Lighting Africa (Africa): www.lightingafrica.org

Preliminary list of technology providers:

1. Philips (Global): www.philips.com/global/index.page
2. Osram (Global): www.osram.com/osram_com

Water Efficiency Technologies

Preliminary list of research institutes/organisations:

1. Healing Water Institute (UK, New Zealand): www.healing-water.org
2. NAHB Research Centre (USA): www.toolbase.org/index.aspx
3. Alliance for Water Efficiency (USA): www.allianceforwaterefficiency.org/default.aspx

Preliminary list of technology providers:

1. Daelyu Industry Ltd (Korea): http://daelyu.en.ec21.com

2. Johnson Controls (Global): http://www.johnsoncontrols.com/publish/us/en.html

Carbon-Sink and Low-Carbon Building Materials & Products

Preliminary list of research institutes/organisations:

1. International Network for Bamboo and Rattan (Global): www.inbar.int/index.ASP
2. Singapore Environment Council (Singapore): www.sec.org.sg

Preliminary list of technology providers:

1. Bamboo Living (USA): www.bambooliving.com
2. ENGRO (Green Concrete) (Singapore & China): www.engro-global.com/index.html

Greening and Building Integrated Greenery Systems

Preliminary list of research institutes/organisations:

1. International Green Roof Association (Global): www.igra-world.com
2. Centre for Urban Greenery and Ecology (Singapore): www.cuge.com.sg

Preliminary list of technology providers:

1. Green China Design (China): http://greenchina.cuberoof.com
2. Elmich Singapore Pte Ltd (Singapore): www.elmich.com
3. Zhimizu Corporation (Global): http://www.shimz.co.jp/english/index.html

Solar Technologies

Preliminary list of research institutes/organisations:

1. International Solar Energy Society (Global): www.ises.org
2. UNIDO International Solar Energy Center for Technology Promotion and Transfer (Global): www.unido-isec.org/englishindex/Index.html
3. Renewable Energy and Policy Network for the 21st Century (Global): www.ren21.net/default.asp
4. Solar Energy Research Institute of Singapore (Singapore): www.seris.sg
5. Sustainable Energy Society of Southern Africa (Southern Africa): www.sessa.org.za
6. Solar Aid (East and Southern Africa): http://www.solar-aid.org

7. Solar Combi + (Europe): www.solarcombiplus.eu
8. Solar Energy Foundation (Sweden in supporting developing countries): http://www.solarenergy foundation.com/sefpurpose.htm
9. Solar Energy Section, Barefoot College (India): http://www.barefootcollege.org

Preliminary list of technology providers:

1. Siemens Solar Industries (Global): http://www.automation.siemens.com/mcms/solar-industry/en/Pages/Default.aspx
2. Solar Dynamics Pte. (The Caribbean): http://solardynamicsltd.com
3. Shanghai Roy Solar Co., Ltd. (China): http://www.roysolar.com
4. SOLID solarinstallation+design (China): www.solidchina.com
5. Midrand Solar Technologies (South Africa): http://www.midrandsolar.co.za

Building Integrated Wind Turbines

Preliminary list of research institutes/organisations:

1. Renewable Energy Research Centre, University of Dhaka, Dhaka (Bangladesh): www.univdhaka.edu/research3/research_centre_details.php?id=6
2. Center for the Study of Wind Resources (CERE), Universidad de Magellanes (UMAG),Punta Arenas, Chile: https://www.umag.cl/en/research.php
3. Global Wind Energy Association (Global): www.gwec.net
4. African Wind Energy Association (Africa): www.afriwea.org

Preliminary list of technology providers:

1. Vestas (Denmark, Global): www.vestas.com
2. Aeolos Wind Turbine (Global): www.windturbinestar.com
3. Eveready-Kestrel (South Africa): www.kestrelwind.co.za

Energy Management and Performance Improvement

Preliminary list of research institutes/organisations:

1. EPC Watch (Global): http://energyperformancecontracting.org
2. Caribbean Hotel Energy Efficiency Action Project (The Carribean): www.caribbeanhotelandtourism.com/CASTchenact.php

Preliminary list of technology providers:

1. Honeywell Building Solutions (Global): https://buildingsolutions.honeywell.com/Cultures/en-US
2. Siemens Building Technologies (Global): www.buildingtechnologies.siemens.co.uk
3. Self Energy Group (Europe and Africa): www.selfenergy.eu

Behaviour Change Catalysts

Preliminary list of research institutes/organisations:

1. Smart House/Smart Grid: www.smarthouse-smartgrid.eu
2. Smart Green Home Consortium (Global): http://smartgreenhome.org

Preliminary list of technology providers:

1. Greenway Reality (Singapore, Denmark & USA): www.greenwavereality.com
2. Pacific Gas and Electricity Company (USA): www.pge.com

Community Based Energy Services

Preliminary list of research institutes/organisations:

1. IEA District Heating and Cooling (International): www.iea-dhc.org
2. BSP – Nepal Bakhundole, Lalitpur,Nepal: www.bspnepal.org.np/introduction.htm
3. Energy Charter Secretariat (Europe and Asia): www.encharter.org
4. Association for the District Heating of the Czech Republic (ADH CR): http://www.tscr.cz/index.php

Preliminary list of technology providers:

1. Terra Humana Clean Technology Engineering Ltd (Hungary): www.terrenum.net/cleancoal

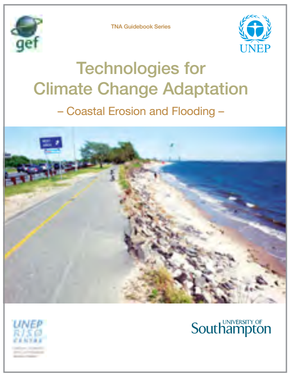
Sustainable Community Design and Practices

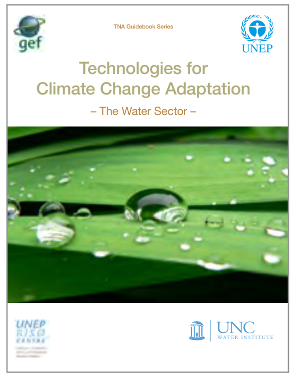
Preliminary list of institutes and supporting organisations:

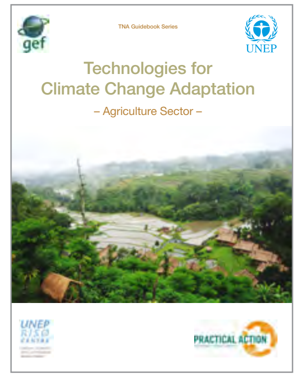
1. BREEAM Communities (UK): www.breeam.org/page.jsp?id=117
2. Global Ecovillage Network (Global): http://gen.ecovillage.org
3. Green Building Council Australia, Green Star Communities (Australia): www.gbca.org.au/green-star/green-star-communities

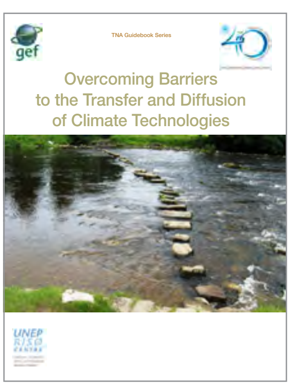
4. Green Communities (South Africa): www.greencommunities.co.za/default.asp
5. Habitat for Humanity (Global): www.habitat.org
6. Sustainable Community Design, University of Manitoba (North America): www.arch.umanitoba.ca/sustainable/contents.htm
7. US Green Building Council – LEED for Neighborhood Development (US and Global): www.usgbc.org/DisplayPage.aspx?CMSPageID=148

TECHNOLOGY NEEDS ASSESSMENT (TNA) GUIDEBOOK SERIES









This guidebook covers a range of building technologies, design principles and practices which can significantly reduce emissions of greenhouse gases, while improving living and working conditions. All the mitigation technologies and practices are dealt with in simple language and approaches for implementing these technologies are also provided. This guidebook will be used by the national TNA teams which consist of stakeholders from government, non-government organisations and the private sector.

This publication is coordinated by Dr. Jorge Rogat and authored by Dr. Wynn Chi-Nguyen Cam with contributions from other experts active in the building sector. Combining the expertise in sustainable built environment and climate change as an architect, researcher and international policy-making facilitator, the author provides a balanced analysis of technologies from both—a climate and sustainable development perspective.

This publication is one of the adaptation and mitigation technology guidebooks, produced as part of the GEF-funded Technology Needs Assessment (TNA) project. This project is undertaken by UNEP and URC in 36 developing countries.

DTU

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http://www.uneprisoe.org/
http://tech-action.org/