FUTURE-PROOFING THE ENVIRONMENTAL PERFORMANCE OF LOW-INCOME HOUSING: A SOUTH AFRICAN CASE STUDY.

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Abstract: *The construction of homes provides social and economic benefits to society, but contributes significantly to environmental degradation. The focus of both international and South African efforts to improve the environmental performance of the residential building sector is household energy efficiency – a valid priority, given that household energy use typically accounts for 80-90% of a home's total life cycle energy. However, as household energy efficiency is attained, the environmental burdens of building materials are gaining in importance and need to be addressed if sustainable housing is to be achieved. Furthermore, the electricity demand of South Africa's low-income residential sector is predicted to remain low, due to affordability issues. By contrast, the building materials demand of the national housing programme would need to increase substantially if the huge housing backlog is to be cleared. This paper reports on a CSIR BE research project which demonstrates how and in what way innovative material technologies could be implemented to foster the delivery of sustainable, low-cost housing in South Africa. International trends in the delivery of sustainable housing were reviewed. A situational analysis, based on a desk-top literature review and three modelling studies, compared the performance of a Standard Subsidised House (SSH) to that of an experimental CSIR House (CH). The results suggest that to deliver sustainable low-cost housing in South Africa, substitution of conventional with innovative material technologies may need to be prioritised over energy efficiency.*

Keywords*: sustainable housing, life cycle, innovative technologies, sustainable materials*

INTERNATIONAL CONTEXT OF SUSTIANABLE HOUSING

The construction of homes provides social and economic benefits to society, but contributes significantly to resource use and pollution. The energy needed to heat, cool and light homes, operate appliances, heat water and cook accounts for between 20-25% of global primary energy use (NHBC Foundation, 2011). Around the world, households account for the largest share of freshwater and raw materials use; and generate inordinate quantities of solid and liquid wastes. The greater part of prime agricultural land lost to farming is used for home building. Nearly 50% of all global greenhouse gas (GHG) emissions are the result of energy use in homes. Furthermore, it is likely that by 2050 the global number of households will increase by 67%; and residential sector GHG emissions will double if allowed to continue unchecked. Thus, for many governments, improving the environmental performance of the residential building sector is central to their ability to meet national sustainable development targets.

To foster sustainable housing, both developed and developing countries are updating their building regulations and codes to include minimum environmental standards. The common environmental issue driving these efforts is current and future household energy efficiency – a valid priority, given that the Use Phase energy of a home typically accounts for 80-90% of the total life cycle energy (Kotaji et al, 2003). For example, Britain's Code for Sustainable Homes (2006) is an environmental standard which is mainly concerned with achieving Use Phase energy efficiency. The key interventions include installation of smart metres, upgrades to insulation and boilers, appliance labelling and promotion of energy efficient lighting. Similarly, as one of the fastest growing economies in transition, India promotes appliance labelling and widespread use of solar water heaters as the ultimate means to improve the environmental performance of the residential building sector.

Figure 1: Generic life cycle stages of a building (adapted from Keoleian et al, 2001)

However, the delivery of sustainable housing requires a life cycle perspective. This is because the life cycle of a typical building includes three phases, namely, the Pre-Use Phase, Use Phase and End-of-Life (EOL) Phase. Therefore, the narrow focus on household energy efficiency during the Use Phase overlooks the energy use and other environmental burdens of the Pre-Use and EOL Phases. These burdens are mainly attributable to the materials life cycle. Their importance is gaining ground as household energy efficiency is attained. When Keoleian et al (2001) compared a standard home (SH) and an equivalent energy efficient home (EEH), a significant reduction in life cycle energy, 60%, was achieved by the EEH over the SH. They also found that as life cycle energy decreased, Use Phase energy decreased and the embodied energy of construction materials increased. More recently, Sartori and Hestnes (2007) validated this result in sixty case studies, despite climatic differences, and regardless of building type and other contextual factors.

This paper reports on a CSIR BE research project which demonstrates how the implementation of innovative material technologies in the context of the national housing programme could potentially future-proof the environmental performance of low-income homes and thereby contribute to national sustainable development targets. The need for a sector-specific approach to sustainable low-income housing is highlighted. The key national policies for delivery of sustainable human settlements are reviewed. The results of three comparative modelling studies are presented and the lessons learnt are discussed.

NATIONAL POLICY REVIEW

Low-cost housing provision is of major importance to government in post-apartheid South Africa. The Constitution, Act 108 of 1996, Section 26, enshrines housing for all as a basic human right. In the first decade of democracy, the national housing programme focussed more on delivering large numbers of low-cost housing units than creating an enabling environment for sustainable housing delivery. Despite this, the vision of completing about 350 000 units per year was not achieved. This is because the rate of growth in the number of households exceeded the pace of completion of new houses. The strong focus on sheer numbers also promoted the use of a standard house plan and specifications informed by conventional material technologies and well-known best practices. The key national policies constituting an enabling framework for the design and delivery of sustainable housing are:

- Breaking New Ground - A Comprehensive Plan for the Development of Sustainable Human Settlements,
- National Housing Code
- Energy Efficiency Strategy of the Republic of South Africa

Breaking New Ground, also known as BNG, moved the national housing programme beyond the mere provision of basic shelter towards a broader national vision of "sustainable human settlements", that is "Well-managed entities in which economic growth and social development are in balance with the carrying capacity of the natural systems on which they depend for their existence" (DHS, 2004). However, the BNG strategy is concerned with the social and economic aspects of sustainability. It refers to the use of alternative material technologies but does not elaborate on how these could serve to improve the environmental quality of homes built through the national housing programme.

The *National Housing Code* sets out minimum norms and standards applicable to dwellings constructed through the national housing programme. The *Technical Provisions* to the *Housing Code* sets out extensive design guidelines on "sustainable energy" and "sustainable water" (DHS, 2009). The *Technical Provisions* point out the importance of selecting construction materials to maximise their contribution to the thermal performance of low-cost housing; and lists construction materials to be avoided for their detrimental effects on human health. The *Technical Provisions* are however silent on the issue of sustainable materials.

The Energy Efficiency Strategy of the Republic of South Africa sets a national, long term target for energy efficiency improvement of 12% by 2015 (DME, 2008). *The Strategy* aims to reduce pressure on the electrical power supply which does not meet the demands of South Africa's economy. In line with international trends, the residential sector-specific energy reduction target of 10% is to be achieved by means of household energy efficiency. The proposed interventions include but are not limited to subsidised solar water heating, environmental labelling of appliances and mandatory application of the national standard *SANS 204 Energy Efficiency in Buildings*. Standards for non-electric stoves were also developed to encourage low-income households to switch to safer cooking methods.

RATIONALE FOR A COUNTRY-SPECIFIC FUTURE-PROOFING APPROACH

Low-income families account for only 10% of the residential sector electricity demand, but represent approximately 50% of South African households. Despite government's commitment to provide free, basic electricity to all poor households, the electricity demand of the low-income residential sector is expected to remain low due to affordability issues (UNEP/CIDB, 2009). The planned electricity price increase of about 25% per year is likely to exacerbate this issue. Reliance on energy sources other than electricity has also been linked to poor air quality in around low income settlements, frequent fire outbreaks, burns and other human health effects. The interventions planned under the EES may protect human health and reduce the incidence of household fires. It may however contribute only marginally to the residential sector energy demand reduction target.

By contrast, cement and cement-based materials, which are energy intensive in their production, are the key building materials for the national housing programme. When Mapiravana (2010) investigated the most widely sold and used building material groups in South Africa, he ranked cement and concrete in first place with a market share of 35%. Although figures are not available to confirm the split in market share, cement-based masonry may account for about 60% of the total market for masonry. In 2006, the split in cement demand between residential and non-residential buildings was 68%: 32% (CIDB, 2007). Figures are not available to confirm the residential sector split in cement and cement-based materials demand between the national housing programme and privately constructed homes.

However, the following suggests that the national housing programme may account for the larger market share, namely:

- The low-cost housing backlog is currently more than 2 million units. Government aims to speed up delivery in order to clear this backlog by 2014.
- Government allocates about 10% of the annual infrastructure budget (about R 10 billion Rand per annum) to housing development.

It is therefore likely that materials manufacturing contributes more to the environmental burdens of South African low-income homes than household energy use. Furthermore, when the input costs of home building are analysed, the split between construction materials and labour is typically 60%: 40% Mapiravana (2010).

Giving priority to the efficient use of cement and cement-based products, or alternatively substituting these with materials known to have lower environmental burdens is therefore likely to yield a range of benefits. These may include energy demand reduction, reduction in local air pollution and human health effects, cost savings and materials savings.

CSIR ADVANCED CONSTRUCTION TECHNOLOGY PLATFORM MODELLING STUDIES

This case study arises out of a Department of Science and Technology contract awarded to CSIR Built Environment in 2008. The contract mandated CSIR BE to develop, test and implement innovative technologies capable of improving the performance of standard subsidised housing built from the National Home Builders Registration Council (NHBRC) approved plan. CSIR BE aimed to achieve comfortable subsidised housing that performs as well as conventional suburban housing, is durable, and quick to build, readily alterable, and easily extendable.

The research project was carried out on the basis of two experimental houses, the standard subsidised house (SSH); and the CSIR house (CH) both of which were built on the CSIR Pretoria test site. Both buildings are based on the $40m^2$ standard plan approved by the NHBRC for subsidised housing. The two houses are distinguished from each by means of the differences in technology of the construction materials. SSH serves as a reference building against which the performance of the new improved version CH can be measured.

SSH was therefore built in accordance with NHBRC specifications. The conventional material technologies which characterise SSH are:

- Substructure – concrete strip foundation on hard core fill, solid concrete block foundation walls and 75mm concrete floor slab on hardcore fill.
- Superstructure – solid concrete blocks
- Finishes – 25mm thick floor screed and StippleCrete to external walls

The innovative material technologies which distinguish CH from SSH are the following:

- Substructure: CSIR 50mm thin concrete raft foundation on stabilised fill
- Superstructure: Modular, hollow concrete blocks; and precast concrete window frames (applied to four out of seven windows to minimise thermal bridging).
- Finishes: Insulated ceiling board; and thermal plaster to external walls

Three modelling studies were carried out to assess and compare the environmental and cost performance of SSH and CH. The results are reported and discussed in the sections below.

Comparative study 1: Whole life cycle resource use and GHG emissions

This study relied on a Life Cycle Assessment (LCA) methodology to compare SSH and CH on the basis of resource intensity (energy, material and water consumption) and contribution to GHG emissions. The temperate climate of Pretoria and the soil conditions of the CSIR test site were assumed to be representative of South African building conditions. The study investigated the Pre-Use Phase and the maintenance materials needs of the Use Phase (Figure 1). The results suggest that the substitution of conventional with innovative technologies results in overall improved environmental performance of a subsidised low-cost house (Ampofo-Anti, 2010):

- **Construction materials:** The Pre-Use Phase of CH required about 35% less material resource input by weight as compared to SSH. The significant material demand reduction is due to savings on concrete blocks, sub-structure concrete, foundation wall, sub-structure mortar and floor screed. Over a building service life of 50 years, CH requires about 50% less maintenance materials input by weight due to the use of lighter finishing materials. The substitution of short-lived with long-life finishing materials would further increase the advantages of CH over SSH.
- **GHG emissions:** As compared to SSH, CH contributes less to climate change. The potential savings are about 685kg CO_2 equivalents. In the large scale context of the national housing programme, this saving will translate to substantial quantities of national GHG emissions avoided.
- **Energy:** As compared to SSH, the embodied energy of CH is higher. The increase in embodied energy is caused by the insulated ceiling board which relies on energy as feedstock. The potential increase in embodied energy is about 70kg oil equivalents. The slight increase in embodied energy per house needs to be viewed against the overall environmental gains to be made if CH were to be substituted for SSH.
- **Water:** As compared to SSH, CH contributes less to water demand. The potential savings are about 20m^3 of water. This should translate to a substantial water demand reduction in the large scale context of the national housing programme. The use of concrete and other cement-based materials in the Pre-use Phase accounts for about 80% of the water demand, suggesting that building contractors have a key role to play in construction-related water

conservation. The water demand of CH could therefore be lowered further by minimising the use of concrete, mortar, screed and plaster.

Comparative study 2: Use Phase energy and thermal performance

To save costs, the standard house plan of the NHBRC does not make provision for ceiling or wall insulation. SSH is therefore subject to large, daily variations in temperature. It is common practice for the occupants to burn coal or wood inside the dwelling for space heating. However, the building envelope has a limited ability to retain heat, thus very little can be done to maintain a reasonable interior temperature on the coldest days and nights of the year. The cold conditions which result, and the prolonged exposure to smoke, leads to increased levels of sickness and place a financial burden on the poorest section of society.

The following measures were applied to improve the energy and thermal performance of CH:

- Appropriate north-south orientation;
- Appropriate roof overhang combined with north-facing windows;
- Cavity walls (modular, hollow concrete blocks);
- Insulated ceiling; and
- Insulated external walls (thermal plaster).

The study used computational modelling to quantify and compare the thermal performance of SSH to that of CH. The study found that (Osburn, 2010):

- CH needs only 40% of the operating energy of SSH to maintain a comfortable indoor thermal environment.
- CH would require active heating on the coldest days of the year. The variations in the indoor temperatures are however much lower – the indoor temperature did not exceed 25°C on the warmest days. This is a comfortable temperature for most individuals.
- The thermal performance of SH can be improved considerably by the addition of a carpet on the floor and the provision of ceiling or wall insulation.

Table 1: Energy loading of SSH and CH (Osburn, 2010)

House type	Heating load (GJ)	Cooling load (GJ)	Total load (GJ)
Subsidy House (SH)	12.32	6.78	19.10
CSIR House (CH)	7.66	0.00	7.66

A switch in the subsidy house design from SSH to CH will therefore translate to a number of economic and environmental benefits. These include savings on the energy bill for poor families; improved air quality and human health; an overall decrease in the operational energy demand of the low-income residential sector; and a corresponding decrease in the GHG emissions of the sector.

Comparative Study 3: Pre-use Phase costs

The costs of labour and materials for SSH and CH were monitored and documented throughout the building process. Study 3 was limited to the Pre-Use Phase only thus no attempt was made to predict the cost of building maintenance and repair over the estimated building life cycle of 50 years. The results show that as compared to SSH, CH costs R 18 856.11 or 41.43% more. The substructure and services components of CH cost less than the equivalent components for SSH. However, the labour and materials costs for the superstructure, roofing and finishes of CH all cost more than the equivalent components of SSH.

Table 3: Comparative costs of SSH and CH (De Villiers, 2011)

Ref	Work description	Subsidy house (SH)			CSIR house (CH)			CH as % of SH
		Labour cost	Material cost	Total cost	Labour cost	Material cost	Total cost	
1	Substructure	2 710.35	7 078.44	9 788.79	2 608.66	6 704.77	9 491.58	96.96
2	Superstructure	3 237.00	13 960.69	17 197.69	4 518.00	25 773.35	30 291.35	176.14
3	Roofing	1 485.00	7 157.04	8 642.04	3 522.00	10 596.72	14 118.72	163.37
4	Finishes	2 697.50	4 514.10	7 211.60	3 696.25	4 343.63	8 039.88	111.49
5	Services	1 391.25	1 281.20	2 672.45	1 283.25	1 143.90	2 427.15	90.82
	Totals	11 521.10	33 911.47	**45 512.57**	15 628.15	48 562.37	**64 368.68**	141.43
					135.65%	142.87%	**141.43%**	

As an experimental work, direct comparisons on time and labour may not be relevant. The building team erected SSH without any need for instruction or supervision. Erection of CH on the other hand entailed training, demonstration and instructions throughout. A later attempt to build CH on the CSIR Kleinmond site showed that all the walls could be built in one day, suggesting that the additional costs due to labour can be easily addressed with appropriate training. The higher cost of materials for CH is partly due to the thermal plaster and insulated ceiling board which were added to CH, but not to SH; and partly due to the higher cost of the modular, hollow concrete blocks. The increase in time and cost also needs to be viewed against the considerable gains in environmental performance demonstrated by the first two modelling studies (de Villiers, 2011).

CONCLUSION

The CSIR investigations presented in this paper lead to the conclusion that to future-proof the environmental performance of the low-income residential sector, the national housing programme should prioritise the substitution of conventional with innovative material technologies. This assertion was put to the test through three modelling studies based on experimental buildings, which evaluated the life cycle resource use and GHG emissions; Use Phase energy demand and thermal comfort; and initial building costs. Each of the three studies compared conventional material technologies, as represented by the NHBRC's standard subsidy House (SSH), to innovative technologies as represented by a new improved version, the CSIR House (CH). The results of the studies suggest that potentially:

- The mass of materials used to build two units of SSH could build three units of CH. CH is also likely to require about 50% less maintenance materials by mass when compared to SSH

- The embodied energy of CH is likely to be higher than that of SH. However, the material-intensity, water demand and GHG contributions of CH are all likely to be lower than that of SH. The embodied energy of CH could be improved by selecting finishes which are highly durable or maintenance-free

- A switch in technology specification from SSH to CH will translate to a number of economic and environmental benefits. This is because CH will need only 40% of the operational energy of SSH to maintain a comfortable indoor environment

- The initial building cost will be higher, but CH can be erected faster than SSH. The increase in cost needs to be viewed critically against the environmental benefits and shorter lead time highlighted by the three studies.

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