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Cost–benefit analysis of energy efficiency in urban low-cost housing

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This cost–benefit analysis study considered energy-efficiency measures in low-cost housing, primarily standard 30 m^2 Reconstruction and Development Programme (RDP) houses. The three packages of interventions that improve the thermal performance of the houses (ceilings, roof and wall insulation, windows and partitions) were found to be economically attractive both from a national and a household perspective. The net benefits from the whole package for a standard RDP home is about 10 per cent of the value of the housing subsidy provided by the government. The same interventions applied to informal housing appear more costly because the lifespan of shacks is taken to be five years. Row houses are particularly attractive, although their social acceptability requires further study. Compact fluorescent lamps and solar water heating are also attractive because of the energy savings they deliver. Apart from saving money, all these measures improve the quality of life of households by increasing comfort and decreasing indoor air pollution. Although the measures have a net social benefit, it does not mean that poor people can afford them. Energy-efficiency measures tend to have high capital costs, while the benefits are spread over many years. With their high discount rates, consumers are often not able to wait for future savings, nor do they have access to capital for investment. Based on our analysis, however, a capital subsidy of between R1 000 and R2 000 (not the full capital cost) is all that would be required to make these measures attractive to poor households across a range of regions and income groups. The no-cost measures of northern orientations: climatically correct window size and placement, as well as the appropriate wall and roof colour have a thermal running cost and environmental impact.

1. INTRODUCTION

A major advance in research on energy policy over the past 20 years is the growing body of literature showing how saving energy, rather than supplying more of it, can be the most cost-effective path for development – see, for example, Reddy & Goldemberg (1990), Lovins & Lovins (1991) and Kats (1992). In countries such as South Africa, where the gap between access to affordable energy and the demand for clean energy is very large, energy efficiency has the potential to accomplish multiple social and economic objectives.

Previous South African studies have shown a significant potential for energy efficiency across a range of sectors, but the costs are not well understood (Thorne, 1995). The impacts of energy efficiency on the low-income residential sector are particularly

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important in the light of social priorities for upliftment and empowerment of the poor. A series of research papers from the Energy and Development Research Centre (EDRC) have applied traditional cost–benefit analysis (CBA) to some energy-efficiency interventions for the urban poor at a national level (Thorne, 1996; Clark, 1997; Simmonds, 1997; Van Horen & Simmonds, 1998; Spalding-Fecher et al, 1999). The present analysis takes such studies a step further by including a wider range of interventions and a disaggregated analysis at the household level. The basic methodology, however, remains the same.

The key question is whether energy efficiency in low-cost housing is a good investment, and from whose perspective. Even if it is a good investment from a social perspective, would poor people be able to afford it? If not, what magnitude of capital subsidy would be required to make it more attractive? Also, does the inclusion of external costs (from local and global pollution) make a difference to the calculations? This study seeks to answer these questions in order to identify the packages of energy-efficiency interventions that require financing.

This article is based on part of a major study undertaken by the EDRC, the Universities of the Witwatersrand and Pretoria and PEER Africa for the interdepartmental Environmentally Sound Low-Cost Housing Task Team in South Africa, to analyse systematically and communicate the economics and environmental implications of energy efficiency in low-cost housing. The article addresses only the economic and financial impacts of the interventions; the environmental impacts and a detailed technology assessment are contained in the main research report (Irurah, 2000). After presenting the methodology and main assumptions used, we present the CBA results from a national and social perspective. This is followed by an analysis of affordability from a consumer perspective, including quantitative estimates of the government support needed to implement these programmes. We conclude with policy recommendations and an assessment of future research needs on energy use in low-cost housing.

2. METHODOLOGY AND DATA OVERVIEW

The study considers the impact of energy-efficiency interventions in low-cost housing, focusing on interventions in the building shell. Space heating or thermal interventions include a ceiling, roof insulation, partitioning, appropriate window size and wall insulation. A ‘package’ of all these interventions is considered, applied first to a 30 m^2 Reconstruction and Development Programme (RDP) house (through the RDP the government aimed to build at least one million houses between 1994 and 1999), and also to row (semi-detached) houses and shacks. In addition, we analyse more efficient lighting and water heating using compact fluorescent lamps (CFLs) and solar water heaters (SWHs), respectively.

The energy use considered was only the direct energy consumption to provide energy services (fuel combustion and electricity usage), and did not include the embodied energy of the housing shell or any appliances. Most of the interventions focus on improving formal, low-cost housing, or what is provided through the national government housing subsidy programme. In the context of housing policy, a variety of housing styles and sizes have been delivered through the RDP programme, but this analysis focused on the most commonly implemented option to date.

Standard RDP houses typically incorporate no energy-efficiency interventions. The main reason for this is that the major delivery system is contractor-built housing. For contractors, there is no incentive to invest in energy efficiency, because they cannot capture the energy savings or other benefits, such as reduced health costs. For community-built housing, on the other hand, there is a greater incentive for the builders themselves to invest in interventions that will save them money in the future.

The first major question about the energy-efficiency measures is whether the project results in net economic benefits for the country as a whole. This involves a discounted cash-flow analysis of all the financial and social costs associated with the intervention. The integrated energy-planning approach calls this the 'total resource cost test', calculating the total cost of providing energy services with and without the project in question (CEC, 1987). This national perspective in the analysis is based on total resource costing, although only incremental changes in the cost and benefit streams are presented.

Even if interventions have national benefit, are they affordable for poor households? The second major issue is whether consumers would see the interventions as beneficial, given their needs and financial situation. The simplest technique is to perform the discounted cash-flow analysis using a consumer discount rate and only those costs that the consumer actually pays, which would exclude external costs. In electricity-efficiency analysis this is called typically the 'consumer revenue test' (CEC, 1987).

2.1 Cost–benefit analysis methodology

CBA is a tool for assessing the viability of different investments that considers the future realisation of costs and benefits. In general, the appraisal of capital investment projects is undertaken using discounted cash-flow analysis. This approach is adopted in the methodology described here. In this sense, evaluating an investment in energy-efficient or environmentally sound housing is no different from evaluating any other type of capital project (Davis & Horvei, 1995). A narrow use of CBA, however, excludes consideration of external costs. This study has extended the analysis to cover both the national and consumer perspectives, as well as including a wider range of costs and benefits than a conventional financial analysis. In addition, other parts of the broader study deal qualitatively with environmental impacts not captured in the CBA. The consumer perspective in this instance is obtained by using a different discount rate, not by an empirical examination of consumer behaviour.

Using the data described in the Appendix, we used the following steps in this analysis:

1. Estimate the energy savings from each intervention, by region based on the model of an improved house (Holm, 2000a). These savings are expressed as percentages of energy consumption.
2. Estimate the incremental capital cost of the intervention, as well as replacement costs and non-energy savings (also based on the work of Holm, 2000a).
3. Develop a matrix of fuel consumption patterns (for electricity, wood, coal, gas and paraffin) by region.
4. Convert the percentage energy savings to energy units of kilowatt-hours.
5. Convert energy savings to rands, using fuel price data.
6. Estimate external costs, both for global effects (such as greenhouse gas emissions) and local impacts, expressed as rands per gigajoule of energy.

7. Discount all costs (incremental capital and operating expenses) and benefits (energy savings, decreased operating costs and avoided external costs) to present value.
8. Deduct costs from benefits to derive net present value.

This analysis was conducted initially at the household level and then aggregated nationally. We first calculate the net present value (NPV) for individual households in different regions, but still using a social discount rate and all social costs. National NPV is derived from household NPV multiplied by the number of households in the target group in each region (or income group). The target group differs according to whether the interventions are introduced upfront in new houses, or by retrofitting existing houses.

An intervention passes the total resource cost test if the present value of all the benefits exceeds the present value of all the costs. We also look at how this result varies across regions and income groups, based on differences in fuel-use patterns and local prices of energy and construction materials in different climatic regions.

2.2 Discounting and inflation

A critical factor in CBA is the discount rate. Using a discount rate that converts future money into present value, one can compare costs and benefits spread unevenly over time. The social discount rate is used in this case to reflect the opportunity cost of capital to society as a whole, rather than to individuals or specific institutions. We use 8 per cent as the social discount rate, following the practice of the government and the South African Reserve Bank for evaluating infrastructure projects (Davis & Horvei, 1995). Poor households, however, do not have money to invest upfront. In fact, many of them rely on especially punitive sources of capital such as hire purchase and so-called ‘loan sharks’ (see Banks, 1999). This is reflected by using a consumer discount rate of 30 per cent for the analysis from the consumer perspective. All current values are given in 1999 rands, corrected for inflation when the original sources are from different years (SARB, 1999). The study does not include municipal infrastructure savings, as they do not accrue to the consumer.

2.3 Data, assumptions and data limitations

The data required for the CBA included energy savings and cost inputs, fuel-use patterns, fuel prices, external costs of energy and housing stock and backlogs. Greater detail on the data and assumptions is provided in the Appendix.

All interventions are considered over 50 years, as this is (optimistically) assumed to be the standard economic life of a low-cost house. If the intervention must be replaced before 50 years, those future replacement costs are also included in the analysis.

Three major regions are considered, represented by Cape Town, Durban and Johannesburg. Provinces included in the three regions are Western, Northern and Eastern Cape (region U1), Gauteng and Mpumalanga (region U2) and KwaZulu-Natal, Northern Province, Free State and North West (region U3). These regions reflect different climatic demands placed on housing, and the economic and social factors that lead to differences in fuel consumption and prices. Because of the limited data available on rural energy consumption patterns in different regions, as well as the

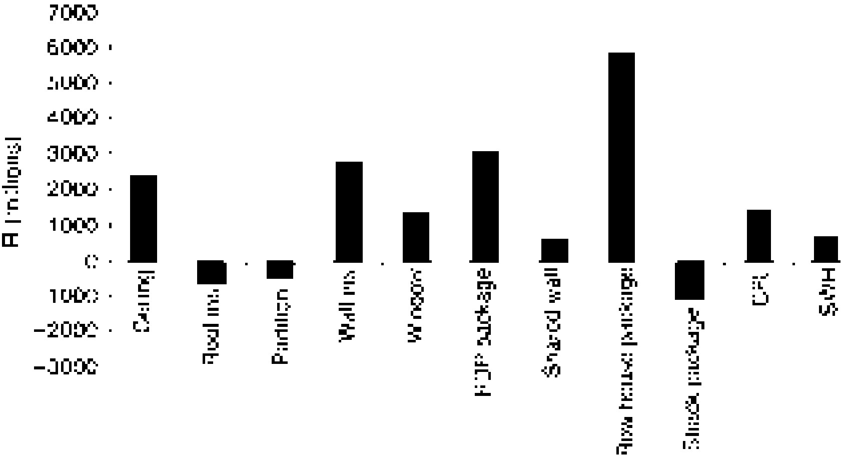

Figure 1: NPV of energy-efficiency interventions nationally, assuming social discount rate and including externalities (1999 Rands)

relatively larger urban housing backlog, the focus of the study was on poor urban households.

The major challenge in collecting the input data for the cost–benefit analysis was the level of disaggregation by region, fuel, income group and end-use. No single dataset exists which considers all the above factors at once. It was therefore necessary to combine data from a number of different sources to approximate the desired level of detail. In some instances, this limitation lies in the fact that data are simply not recorded or analysed at this level of disaggregation in national studies.

3. RESULTS FROM A SOCIAL PERSPECTIVE

Figure 1 presents the national NPV for each intervention, i.e. aggregated across all regions and fuel types, and using the appropriate target group for the total potential number of homes where the intervention can be applied (Figure 1).

Ceiling, wall insulation and window size taken individually, as well as the full packages for RDP and row houses, show substantial positive economic benefits, even without considering externalities. This means that they are relatively low cost (including capital savings for the windows), with significant energy savings over the life of the building. While partitions and roof insulation make sense as part of a package, their specific incremental energy savings are small; on their own, they would therefore not be economically viable. Note that roof insulation is always considered on top of a ceiling, thus it is only credited with the incremental energy savings above a ceiling only, but incurs the full cost of the insulation.

The shared-wall intervention has positive economic benefit, because it avoids part of the cost of the housing shell, as well as energy consumption. The national net benefit for the package of thermal interventions in row houses is the highest discrete intervention analysed. The savings on building costs are significant, adding to the energy cost savings. However, the social acceptability of this intervention needs to be explored. While there is little doubt that row housing, which is more dense than single family housing, is economically and environmentally beneficial, it tends to be associ-

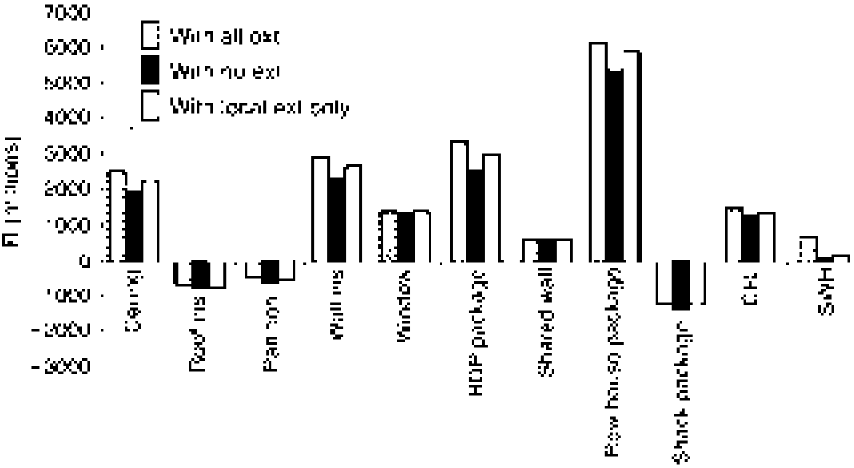

Figure 2: NPV of interventions at national level and the implications of externalities (1999 Rands)

ated with public housing and hostels, and the question here may relate more to acceptability than affordability.

Interventions in informal housing appear costly from a national perspective (Figure 1). This is due in large part to the much shorter life assumed for shacks (five years as against 50 years for formal housing). This is not simply a technical or an engineering assumption, but could also relate to lack of security of tenure and low desirability of continuing to live in shacks. Shacks represent a wide range of alternatives, of which only one has been modelled here; others could include improving security of tenure. The stream of benefits is for a shorter time and the present value of savings is lower. This points to the need to move people into formal housing with secure property rights as soon as possible, but also to explore low-cost insulating materials.

Solar water heating is attractive if one considers local impacts of energy use, and even more so if global impacts are included. The local avoided external costs are not very large since the geysers they would replace are electric, and the incremental capital cost (including the back-up) are high.

While the interventions clearly have the most economic benefit when we take the external costs of energy into account, the difference is relatively minor, except where the benefit is relatively small (as for solar water heaters – see Figure 2). This is understandable, as the majority of the energy savings from these interventions are electricity savings. Previous research on the external costs of energy has attributed much higher health and environmental impacts to non-electric household fuels than to electricity (Van Horen, 1996a, 1996b).

Table 1 shows the average NPV per household, using the same social discount rate and assumptions as above. The net benefits from the whole package of interventions for standard RDP homes are in the order of 10 per cent of the value of the housing subsidy provided by the government, while benefits for the row house package would be almost double that. Even those interventions that have a net cost are less than R800 per household.

At the household level, many of the inputs to the social NPV vary by region – climatic

Table 1: NPV per household for each intervention averaged across regions including externalities (1999 rands)

		Roof		Wall		All SH	Shared	All SH	All SH		
	Ceiling	ins.	Partition	ins.	Window	RDP	wall	Row	Informal	CFL	SWH
NPV	881	2 232	2 230	1 026	688	1 625	298	3 023	2 778	509	351

Note: SH 5 space heating; CFL 5 compact fluorescent lighting; SWH 5 solar water heating.

conditions, fuel prices and fuel-use patterns, for example. It is therefore useful to see whether the results of the cost–benefit analysis vary significantly across regions. The regional household NPV comprises the homes using different fuels in each region, weighted by the share of homes using that fuel in each region. Figure 3 illustrates this variation for each intervention.

Perhaps the most interesting result is how little the NPV varies across regions. This is partly because the region with the coldest climate, and hence the largest potential for energy savings (Johannesburg), is also the region with the highest capital costs (e.g. because thicker insulation is required). Part of the variation is also due to the lower prices for electricity in Johannesburg – whose municipalities are closer to the sources of generation and have more industrial customers to cross-subsidise residential tariffs. This is most evident in the analysis of solar water heaters, where the present value of electricity savings, and hence the NPV, varies by as much as R600 across regions. In no cases, however, are there interventions that make sense in one region that do not make sense in another.

4. THE CONSUMER PERSPECTIVE – WHAT IS AFFORDABLE?

While a particular intervention may be attractive from a traditional CBA point of view, it may nonetheless be unaffordable for the target households. Since this article focuses on low-cost housing, this is an important consideration. The basic problem is that poor households have negligible savings to invest in decent shelter incorporating energy-

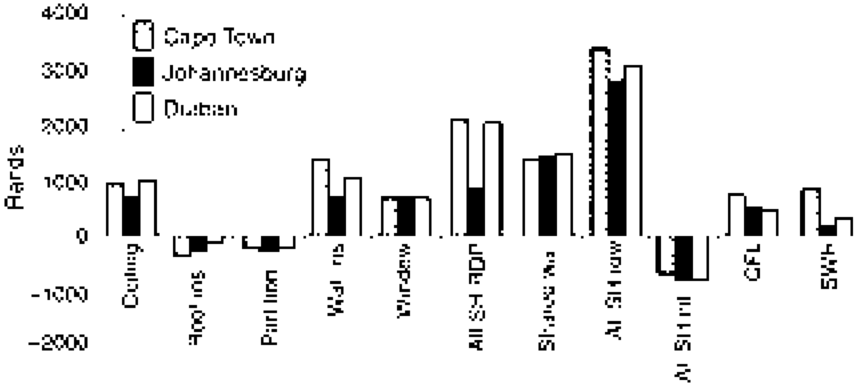

Figure 3: NPV per household by region including external costs (1999 rands)

Table 2: NPV per household at the consumer discount rate (30 per cent) for each intervention and region excluding external costs (1999 Rands)

Consumer discount rate	Ceiling	Roof ins.	Partition	Wall ins.	Window	All SH RDP	Shared wall	All SH Row	All SH Informal	CFL	SWH
U1 (CT)	2 481	2 395	2 333	2 212	604	2 898	1 146	870	2 979	114	2 729
U2 (Jhb)	2 530	2 389	2 335	2 938	603	2 1 716	1 143	669	2 1 048	57	2 827
U3 (Dbn)	2 461	2 219	2 317	2 35	583	2 518	1 136	994	2 1 022	60	2 621

efficiency modifications; neither do they have access to low-cost credit. This can present a problem, because energy-efficient technologies typically have high initial costs, followed by low recurring costs. Less efficient technologies often cost less upfront, but become more expensive through higher operating costs. We ask first whether consumers are likely to see an overall benefit from these interventions, and then look more carefully at what magnitude of support would make the interventions ‘affordable’ for the urban poor. Affordability was measured by the capital subsidy that would be required to induce consumers to invest in energy efficiency on their own.

Table 2 presents the results of the discounted cash-flow analysis using a consumer discount rate and excluding any external costs (because these accrue to society rather than to only the individuals in the target groups). Not surprisingly, most of the interventions do not yield a net benefit when a 30 per cent discount rate is used – the future energy savings simply have much less value to consumers with high discount rates. The reason why changed window size, a shared wall and the row house still have a positive NPV is because they do not require additional upfront costs but, in fact, save money when the house is built. CFLs, if purchased at the bulk prices that Eskom is projecting for its Efficient Lighting Initiative, are also cost-effective, even at a high discount rate.

Although it is clear that overall energy-efficiency interventions may be difficult for some poor consumers to finance, we need to take one additional step to see whether some income groups might be able to afford the interventions. In addition, the policy-relevant question is what incentive would be required by these consumer groups to make socially beneficial energy-efficiency investments worth their while? In response, we developed a simple framework for assessing affordability, one which considers both the saved energy costs, which vary by income group, and the initial costs of energy efficiency. We ask what capital subsidy is required to make energy efficiency attractive to poor households, given their high discount rate.

The capital subsidy required is the difference between the incremental capital cost of the efficiency intervention, and the present value of the future savings, valued at the consumer discount rate. In other words, consumers do see some value in future energy savings, so it is not necessary for the government (or another entity) to fully subsidise the measures. Only where the incremental capital cost is greater than the consumers’ valuation of their savings will the subsidy be required to make up the difference.

The income groups used for this analysis are based on data reported from the study by the Southern African Labour and Development Research Unit (SALDRU) in 1993, as cited in Simmonds & Mammon (1996). Table 3 shows the income groups and

Table 3: Energy expenditure by household expenditure/income groups

	Income group by per household expenditure (R/month)	Total household expenditure (R/month)	Total fuel expenditure (R/month)	Fuel expenditure as a percentage of total household expenditure per month
Less than	600	586	82	11
Less than	1 200	1 041	71	6
Less than	1 800	1 286	87	5
Less than	2 400	1 526	89	5
Less than	3 000	1 727	96	4
More than	3 000	3 150	145	4

Source: Own analysis, based on Simmonds & Mammon (1996: Table 2.11).

expenditure by end use for each group, clearly highlighting the greater energy burden of the very poor. For the affordability analysis, per capita income data were converted to household income, assuming six people per household.

Table 4 shows the estimated annual energy expenditure for these income groups, based on how much they spend on different end uses. Here we assume six people per household, and total fuel expenditure as 25 per cent for space heating, 40 per cent for water heating and 5 per cent for lighting (Simmonds & Mammon, 1996: Table 5.5). Family size may well be affected by the spread of HIV/AIDS. Indeed, the pandemic is also expected to have an impact on household income, as young working adults are particularly vulnerable. This could exacerbate the problem of affordability in future.

The capital subsidy was estimated by first establishing the present value (PV) of the energy savings at the consumer discount rate over the life of the project. The PV was then deducted from the incremental capital cost of the intervention to arrive at the capital subsidy required. Since both the energy savings and the capital costs differ regionally (at least for some interventions), it was necessary to differentiate results for the three regions.

Note that many consumers would still need access to consumer credit,

Table 4: Estimated annual energy expenditure by end use and income group

	Income group by per household expenditure (R/month)	Space heating expenditure (R/annum)	Water heating expenditure (R/annum)	Lighting expenditure (R/annum)
Less than	600	246	492	49
Less than	1 200	214	428	43
Less than	1 800	262	524	52
Less than	2 400	266	533	53
Less than	3 000	288	576	58
More than	3 000	435	869	87

Source: Own analysis, based on Simmonds & Mammon (1996: Table 2.11).

however expensive, to finance the balance of the incremental capital costs after the subsidy has been provided, but they would be willing to pay back this capital from their future energy cost savings. The average capital subsidies that are required across all regions are presented in Table 5.

Those interventions that are already attractive, even when using a consumer discount rate – window sizing, shared walls, the row house package and CFLs – obviously do not require any capital subsidy. The variation of capital grants required for different income groups is not large for most interventions. The exception relates to informal houses, where the capital subsidy required to make the package attractive is about twice as high for the poorest households as for those earning between R2 400 and R3 000 per month.

Some design options, such as proper building orientation (approximately 15° north), environmentally appropriate window size and placement and exterior wall and roof colours, require no additional building costs. However, their non-observance causes long-term losses to the users of the building and to the country. No subsidies should be granted if these no-cost options have not been implemented.

For the 30 m^2 RDP house, a capital subsidy of around R1 000 appears to be required to make the package attractive to households. In the context of housing subsidies, this would be a modest amount in view of the substantial economic and environmental benefits. It should be remembered that this is not the full incremental capital cost, but a subsidy that would make the intervention attractive to households. Mechanisms for financing the incremental capital cost (over and above the status quo subsidy), as well as the capital subsidy, should be a subject for further studies.

5. CONCLUSION: POLICY IMPLICATIONS AND RESEARCH NEEDS

Most of the interventions analysed in the study show substantial economic benefits from a national perspective, even without considering the avoided external costs. The thermal improvement ‘packages’ targeted at RDP housing generate some of the greatest benefits for all climatic regions and income groups. The same is true for CFLs and solar water heating.

The packages, however, are not generally affordable for poor households, given their high discount rate. These findings, based on a general cost–benefit analysis (rather than an empirical study of consumer trade-offs), should be tested in future targeted demonstration projects. The fundamental conclusion of the analysis, therefore, is the urgent need to package energy-efficiency standards and programmes with financing alternatives for low-income consumers. Given that the upfront costs of energy efficiency are generally higher than for standard homes (or water heating and lighting systems), it is the role of the government to put in place regulations and incentives to ensure that consumers and, more importantly, contractors, will make the decisions that are also best for society.

The good news is that the amount of grant funding required to assist consumers in investing in energy efficiency is quite modest. For a standard RDP house, a capital subsidy in the order of R1 000 would be enough to tip the scales in favour of consumer investment in efficiency, assuming that other sources of financing are also available to homeowners. This amount would not vary significantly across income groups. An alternative to a subsidy would be low-cost financing for energy efficiency, which in

Table 5: National average capital subsidy required per household for an income group and per intervention (1999 Rands)

	Ceiling	Roof ins.	Partition	Wall ins.	Window	All SH RDP	Shared wall	All SH Row	All SH Informal	CFL	SWH
, R600/m	527	351	288	255	n/a	1 060	n/a	n/a	426	n/a	1 021
, R1 200/m	584	360	298	318	n/a	1 168	n/a	n/a	534	n/a	1 025
, R1 800/m	499	347	284	224	n/a	1 008	n/a	n/a	374	n/a	971
, R2 400/m	492	346	282	216	n/a	993	n/a	n/a	359	n/a	957
, R3 000/m	454	340	276	173	n/a	921	n/a	n/a	287	n/a	888

Note: the full capital cost is higher than the subsidy required; see explanation in text essence gives the consumer the opportunity to borrow at a social discount rate. Local government, in particular, should explore opportunities for attracting climate change funding for such interventions. Local government is the level of government most likely to implement housing programmes in which energy-efficiency interventions can be introduced. Sourcing Clean Development Mechanism (CDM) investment would provide additional funds for the housing subsidy.

The significant economic benefits from row housing (which are almost double that of an energy-efficient standard RDP house) provide a strong argument for the study of social acceptability of this type of housing, possibly involving actual demonstration units.

Some future research needs emerge from the study. While we concluded that energy-efficiency measures in low-cost housing are economically viable, the financial mechanisms required to implement this are part of a follow-on study. In order to consider concrete projects, analysis at the municipal level is important, including municipal infrastructure costs.

The most pressing requirement for advancing research and policy analysis is, undoubtedly, better raw data. There are virtually no up-to-date data on energy-use patterns that look at consumption by end use in different regions and income groups. This is true particularly for rural areas, where there are only patchy quantitative data on fuel use. A key priority for the Department of Minerals and Energy should be developing a common framework for data collection in all energy consumption studies, and accessing significant funding to develop an up-to-date, detailed energy-use database that goes beyond the work of the current National Domestic Energy Database. This would also involve deepening our understanding of the behavioural, social and cultural variables that influence the effectiveness of energy-efficiency measures.

Finally, the analysis of affordability, measured simply here by capital subsidy requirements, could be extended using the concept of income elasticity. A study analysing the fuel expenditure for various income groups based on income elasticity of energy demand could indicate differences in the needs of poorer communities more clearly.

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APPENDIX: SELECTED DATA AND ASSUMPTIONS

A wide range of primary and secondary data were collected to generate the results discussed in this article. The overall method used has been described above. Selected data are included in the appendix, since the results are crucially dependent on it and the underlying assumptions.

A1. Energy savings and cost inputs

A1.1 Improvements in space heating

Most of the assumptions related to thermal improvements are based on the building energy modelling (using Building Toolbox) conducted for the main study (Irurah, 2000). Note that northern orientation and sunshading of north-facing windows in summer were not analysed separately but included in all of the interventions. The thermal improvements were designed to eliminate the need for space heating when used together, i.e. 100 per cent energy savings for all interventions combined. This may well be overly optimistic, because the use of space heating holds both cultural and social meaning, and is not simply a basic economic and health necessity (Mehlwana & Qase, 1999; Mehlwana, 1999). The tables below present the assumptions of incremental capital cost (Table A1), energy savings (Table A2) and operating cost savings (Table A3), based on the outputs of the thermal simulation. Incremental costs refer to the capital cost of the intervention less any capital savings. For example, the installation of a solar heater nullifies the need for an electric geyser if the solar water heater has electrical back-up.

The thermal simulations and cost–benefit analyses assume that thermal efficiency

Table A1: Incremental capital cost per intervention (1999 rands)

	Region			
Intervention	**U1 (CT)**	**U2 (Jhb)**	**U3 (Dbn)**	**Comments**
Ceiling	957	957	957	
Roof insulation	419	419	258	Thickness varied by climate
Partition	362	362	362	
Wall insulation	736	1 474	418	Thickness varied by climate
Window	2 593	2 593	2 593	Reduced total window glazing area
All SH RDP	1 881	2 619	1 402	Includes all five previous interventions – all space-heating interventions in the RDP house
Shared wall	2 1 114	2 1 114	2 1 114	Reduced need for foundation and roof
All SH Row	2 105	2 18	2 380	Includes same as for standard RDP
All SH Informal	1 247	1 247	1 247	

Source: Irurah (2000), Holm (2000a).

Notes: ‘All SH RDP’ combines all five previous interventions into one package of space-heating measures for an RDP house. The first six interventions refer to modifications to a standard 30 m^2 RDP house. The next two refer to a 30 m^2 RDP row house, where ‘shared wall’ shows only the costs and energy savings associated with moving from a freestanding house to a row house design with two shared walls. ‘All SH Row’ includes a ceiling, roof insulation, wall insulation, proper window sizing, and interior partitions. ‘All SH Informal’ includes modifications to a shack, which include a ceiling and exterior wall insulation.

Table A2: Energy savings per intervention (%)

	Region			
Intervention	**U1 (CT)**	**U2 (Jhb)**	**U3 (Dbn)**	**Comments**
Ceiling	45	43	69	
Roof insulation	5	8	12	Thickness varied by climate
Partition	7	8	12	
Wall insulation	61	85	30	Thickness varied by climate
Window	6	11	9	Reduced total window glazing area
All SH RDP	100	100	100	Includes all five previous interventions
Shared wall	15	25	36	Reduced need for foundation and roof
All SH Row	100	100	100	Includes same as for standard RDP
All SH Informal	100	100	100	

Source: Irurah (2000), Holm (2000a).

interventions will last as long as the building itself (50 years), so that there is no need to replace them in the future. The exterior wall insulation and ceiling also provide important benefits in terms of maintenance costs or non-energy operating costs. Insulation can reduce the costs of painting and, more importantly, the need to repair cracks that would allow air to infiltrate. A ceiling reduces interior condensation, which in turn reduces rust and material wear and saves on maintenance. The magnitude of these savings, however, is not clear and, as with many other assumptions, needs to be subject to proper field tests and monitoring. In the absence of clearly disaggregated data, 50 per cent of the annual savings have been apportioned to a ceiling and 50 per cent to wall insulation in Table A3.

Table A3: Non-energy operating cost savings (R/year)

Ceiling	2 93,5
Wall insulation	2 93,5
All SH RDP	2 187,0
All SH Row	2 130,3
All SH Informal	Not applicable

Source: Irurah (2000).

A1.2 Improvements in lighting

Although the initial cost of CFLs is considerably higher than for incandescent lamps, several studies (Praetorius & Spalding-Fecher, 1998; Clark, 1997; Spalding-Fecher et al, 1999) have shown that the resultant energy savings outweigh the additional cost. The assumptions for the CFL, based largely on the Efficient Lighting Initiative, are presented in Table A4 below.

Table A4: Lighting assumptions per bulb

	CFL	Incandescent	Comment
Initial cost (R/bulb)	R27*	R3,00	Bulb and ballast; price indicated is the subsidised price deemed acceptable to customers
Bulb life (hours of use)	8 000	1 000	
Ballast life (hours of use)	40 000	n/a	
Power rating (Watt)	19	75*	75 per cent energy and demand savings
Hours of use (hours/day)	3,2	3,2	
Bulb life (years)	8	0,86	Based on useful life and usage
Ballast life (years)	34		
No. of replacements (bulb)	6		Over 50-year life of building
No. of replacements (ballast)	1		
Replacement cost (R/bulb)	13		
Replacement cost (R/ballast)	30		

Note: *A 75-W bulb here represents a mix of 60-W and 100-W bulbs.

Source: Spalding-Fecher et al (1999).

A1.3 Improvements in water heating

Whether solar water heating without a back-up system can fully replace the service provided by an electric storage geyser is the subject of some debate. While there are examples of homes that have solar water heating in South Africa with no back-up (Holm, 2000b), other analysts and consultants involved in providing domestic SWH to low-income communities point out that often only 60–70 per cent of the energy needed (and hence hot water) can be provided by solar energy, and so some back-up is necessary to guarantee hot water on demand (Morris, 2000; Spalding-fecher et al, forthcoming). Based on recent experience with low-income communities in South Africa, we assume that some back-up is needed, and that 60 per cent of the electrical energy can be saved through a direct solar water heater. The assumptions for a 100-litre heater, which would provide for a family of six, are presented in Table A5.

Table A5: Solar water heater assumptions (100 litre, 1,8 m^2 collector)

	SWH	Electric storage	Comment
Initial cost (R)	R4 000	R2 200	Includes cost of back-up
Life (years)	15	15	
Energy savings	60%		
No. of replacements	2		Over 50-year life of building
Replacement cost (R)	R2 000		

Note: These costs are fairly optimistic. Recent work in the Lwandle community near Cape Town suggested that solar water heaters with electrical back-up might cost R5 500 installed, compared with R1 350 for electric storage geysers, with non-electric back-up being even more expensive (Spalding-fecher et al, forthcoming).

Source: Irurah (2000).

Table A6: Annual consumption for space heating, by region and fuel

	U1 (CT)	U2 (Jhb)	U3 (Dbn)
Electricity (kWh)	388	358	387
Coal (kg)	372	743	248
Wood (kg)	0	0	0
Paraffin (litre)	49	21	23
Gas (kg)	7	2	3

Sources: Own analysis, based on Simmonds & Mammon (1996: 70, 73–6); Afrane-Okese (1998).

A2. Fuel-use patterns in urban South Africa

The fuels considered in this study were electricity, paraffin, wood, coal and gas. Other fuels that were not considered were candles, generators (petrol and diesel) and lead-acid batteries. The study of Simmonds & Mammon (1996) on fuel-use patterns in urban poor South Africa is the main source for fuel consumption data, because it synthesises a wide range of quantitative research (including a country-wide survey by SALDRU) and because it offers a breakdown by region., art

The fuel-use patterns and percentage share of households using particular fuels for different end uses are shown in the tables below, with space heating in Tables A6 and A7, lighting in Tables A8 and A9 and electric water heating in Tables A10 and A11. Note that the consumption data in Tables A6, A8 and A10 represent total annual consumption by households that use a particular fuel. To know the average household consumption across a community, this must be averaged across the share of households using that fuel. For example, households using coal for heating might use several hundred kilograms per month in the winter, but on a national basis only a small portion of households use coal as their only heating fuel. Thus the average per household across the whole country would only be tens of kilograms.

Given that coal is inexpensive primarily in Gauteng and Mpumalanga, and the climate is considerably colder, it is understandable that the coal consumption figures are highest for this region. Both Cape Town and Durban have higher levels of paraffin usage than

Table A7: Share of houses using fuel for space heating, by region (%)

	U1 (CT)	U2 (Jhb)	U3 (Dbn)
Electricity	75	69	54
Coal	2	5	3
Wood	0	0	0
Paraffin	19	23	38
Gas	2	1	0

Source: Own analysis, based on Simmonds & Mammon (1996: 70, 73–6); NER (1998: 16).

Table A8: Annual consumption for lighting, by region and fuel

	U1 (CT)	U2 (Jhb)	U3 (Dbn)
Electricity (kWh)	332	307	332
Paraffin (litres)	123	53	57

Source: Own analysis, based on Simmonds & Mammon (1996: 73–4).

Table A9: Share of houses using fuel for lighting, by region (%)

	U1 (CT)	U2 (Jhb)	U3 (Dbn)
Electricity	80	72	54
Paraffin	16	6	9
Gas	0,4	0,3	0

Source: Own analysis, based on Simmonds & Mammon (1996: 73–4); NER (1998: 16).

Table A10: Consumption for water heating, by region

	U1 (CT)	U2 (Jhb)	U3 (Dbn)
Electricity (kWh)	1,656	1,656	1,656

Source: Own analysis, based on Simmonds & Mammon (1996: 74–6).

Table A11: Share of houses using fuel for water heating, by province (%)

	U1 (CT)	U2 (Jhb)	U3 (Dbn)
Electricity	74	68	31
Coal	0	5	4
Wood	3	1	28
Paraffin	17	23	19
Gas	5	1	2

Source: Own analysis, based on Simmonds & Mammon (1996: 44); Afrane-Okese (1998: 119); NER (1998).

Johannesburg. The low percentage of homes using coal for space heating in Johannesburg is, however, surprising. In a review of the 1993 SALDRU survey, Simmonds & Mammon (1996) observe that it focused more on established households, which are likely to use proportionately more electricity. In addition, the study considered households living in formal housing and not in shacks. In many cases, the move from informal to formal housing also stimulates additional electricity use, although this process is by no means comprehensively understood. Finally, electrification levels are highest in Cape Town, which also explains the higher use of electricity in those households.

While electricity consumption for lighting does not vary significantly across regions, paraffin consumption does. Durban has a lower share of homes using electricity and paraffin for lighting (54 and 9 per cent of total households respectively). A closer observation shows that the remaining percentage of households uses candles for lighting – a resource that has not been included in this cost–benefit analysis.

Even though the water heating energy consumption estimates are based on low overall energy consumption averages (e.g. 345 kWh per month), they are still fairly high. Water heating is taken to be 40 per cent of energy consumption (Simmonds & Mammon, 1996: Tables 5.9 and 5.5).

A3. Fuel prices

Fuel prices vary significantly across regions, because of transport costs, government interventions in pricing, and supply-demand interactions. Table A12 presents the fuel price assumptions used in this analysis.

Coal prices are higher further from mines (Cape Town and Durban), while paraffin prices are higher further from the refineries (Johannesburg). Variations in electricity prices are due both to the different sizes and pricing policies of local distributors, as well as differences in transmission costs (and, hence, purchase costs for distributors) further from the main sources of generation in the north and east of South Africa.

A4. External costs of energy use

The external costs of energy supply reflect the environmental and other social costs associated with their use. They can be especially difficult to quantify in monetary terms, and are usually expressed as ranges rather than precise figures. Previous research on external costs of energy supply in South Africa relates to the environmental costs of electricity generation, costs of fires and burns associated with paraffin use in the home and the costs of illness and death caused by indoor air pollution from coal and wood burning (Van Horen, 1996a, 1996b). This analysis distinguishes between the global external costs associated with greenhouse gases and the local environmental impacts that reflect immediate health impacts from, for example, indoor air pollution.

Local external costs are taken from Van Horen's study of household external impacts and impacts of electricity generation (Van Horen, 1996a). The damage cost of greenhouse gases is estimated at US$6 per ton of carbon dioxide (Pearce, 1995), or R37 per ton at R6,20 per US dollar. The external cost assumptions are summarised in Table A13. For more detail on the calculations, see Spalding-Fecher et al (1999).

A5. Housing stock and backlog

Some of the thermal improvements can easily be applied to both existing and new housing, e.g. ceilings, roof insulation and wall insulation. Partitions, altered window size (and the complete packages that include these), as well as a solar water heater, have their greatest value when applied to new homes, although they could be retrofitted

Table A12: Retail fuel prices as used in the cost–benefit analysis

Region	Elec (R/kWh)	Coal (R/kg)	Wood (R/kg)	Paraffin (R/l)	Gas (R/kg)
U1 (CT)	0,26	0,65	1,47	2,05	6,06
U2 (Jhb)	0,19	0,28	1,24	2,20	6,06
U3 (Dbn)	0,21	0,65	1,70	2,05	6,06

Sources: Gas, coal and paraffin prices based on DME (1999); wood prices from Simmonds & Mammon (1996); electricity prices from Mavhungu (2000) and Simmonds & Mammon (1996).

Table A13: External cost assumptions by fuel (1999 Rands)

	Local impacts		Greenhouse gas impacts		Total external cost	
Fuels (units)	R/GJ	R/unit	R/GJ	R/unit	R/GJ	R/unit
Electricity (kWh)	2.6	0.01	10.7	0.04	13.3	0.05
Coal (kg)	4.7	0.13	3.9	0.10	8.6	0.23
Wood (kg)	25.7	0.40	0	0	25.7	0.40
Paraffin (litre)	53.6	2.04	2.7	0.10	56.3	2.14
Gas (kg)	*	*	2.1	0.10	2.1	0.10

*No research available on local impacts of LPG.

Sources: Spalding-fecher et al. (1999), Van Horen (1996b), IPCC (1996), and Pearce (1995).

at higher cost. For the latter, therefore, we need an estimate of the backlog to be met by the mass housing programme, but for the former we must know this and also the existing stock of formal, low-cost housing. Low-cost housing was interpreted as costing between R7 500 and R17 250 and fully funded by government subsidy (Hendler, 2000). Energy-efficient lighting can, of course, be applied to all existing and new homes.

Housing backlogs per province totalled just over 2,6 million (Hendler, 2000; SAIRR, 2000) in mid-1998, while a more recent estimate from the national Department of Housing was 2,78 million (Bosch, 2000). Based on the rapid growth of urban informal settlements, we assumed that roughly three-quarters of this backlog was in urban areas. No detailed urban/rural breakdown was available from the Department of Housing.

We estimated the formal, low-cost housing stock from the cumulative construction of low-cost homes since 1960. Only for the period 1997–2000 was there a provincial breakdown (Hendler, 2000). Other periods were assumed to follow the same trend, as a first approximation (SAIRR, 2000: 166, citing the Department of Housing). We used recent housing subsidy allocations to estimate the rural/urban breakdown of construction, and assumed the contribution of the 1977–94 period to urban housing (for which no official data are available) to be minimal, given the government policy during that period. Finally, the most recent data available on informal houses were from the 1996 Census (SSA, 1996). The consolidated estimates, apportioned by region, are shown in Table A14.

Table A14: Number of houses in target group for each intervention, per region ('000)

	RDP 30 m^2 house – space heating					Row house – space heating			Informal house	Lighting	Water heating
	Ceiling	Roof ins.	Partition	Wall ins.	Window	All All SH RDP	Shared wall	SH Row	All SH Informal	CFL	SWH
U1 (CT)	658	658	430	658	430	430	430	430	334	658	430
U2 (Jhb)	916	916	709	916	709	709	709	709	562	916	709
U3 (Dbn)	1 078	1 078	812	1 078	812	812	812	812	555	1 078	812

Sources: Own analysis; Hendler (2000); SAIRR (2000), citing data from the Department of Housing; SSA (1996).