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Enhancing the efficiency of formal low-cost houses by the development of a new low-cost ceiling system

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Abstract
Existing formal low-cost houses in South Africa have been shown to be very thermally and energy inefficient. This could be problematic for the country since the government has promised to build roughly 3 million more of these houses in the near future. Inefficiency in these houses can be effectively addressed by installing ceilings, but the cost thereof is unfortunately too high to be affordable to the applicable sector of the population. New options need to be considered to reduce costs.

Research has shown that practically any material can be used as a ceiling if it provides a barrier to heat flow and eliminates infiltration. The material should ideally possess good thermal properties and comply with standard building regulations, but most importantly, it must be very cheap and easy to install. The low-cost ceiling proposed in this paper has all of these attributes, and installation thereof could result in substantial energy savings, improved indoor comfort, and a better quality of life.

Keywords: low-cost housing, low-cost ceiling system, energy efficiency, installation, thermal efficiency

1. Introduction

Approximately 20% of South Africa's population is currently housed in formal low-cost dwellings (BMI, 1992), and studies have shown that these dwellings are very energy inefficient. When the current administration came to power and introduced the Reconstruction and Development Program (RDP), they promised to build 3 million more of these houses over the next decade to alleviate South Africa's housing shortage (ANC, 1994). If these new houses are built along the lines of the existing formal low-cost houses, then they will be just as energy inefficient.

Several techniques can be applied to new or existing houses to make them more energy efficient, the most effective of which involves changing the exterior colour of the house, employing ventilation control, and installing a ceiling. Extensive research has been conducted in this field in order to compare the effect of each of these measures, and the results obtained from this research will be discussed briefly in this section.

The exterior colour of a house, or any building for that matter, plays an extremely important role in its thermal and energy efficiency. Van Wyk and Mathews (1995) have shown that winter heating requirements can be reduced by up to 34% if a dark colour is applied to the exterior of a formal low-cost house. While this does represent a substantial energy saving, the saving doesn't justify the cost of changing the colour of the house, or compensate for the adversely affected summer indoor conditions.

Rousseau and Mathews (1994) have shown that infiltration rates into formal low-cost houses are fairly high, and that the cooking and heating appliances used in these houses can raise the rates even further. By eliminating infiltration, which is simply a matter of filling any gaps between the walls and the roof of the house, winter heating requirements can potentially be lowered by up to 15%.

Many formal low-cost houses are built with the option of installing a ceiling at a later stage, but unfortunately the vast majority of these houses are never fitted with ceilings. Simulations performed in the past to determine the effect of this measure have revealed that winter heating requirements can be reduced by up to 74% in houses with a ceiling (Rousseau and Mathews, 1994). This is a huge reduction in energy expenditure, and far and away the most effective way of improving energy efficiency in formal low-cost houses.

The fact that ceilings are so effective at increasing winter heating energy efficiency (Plank et al,

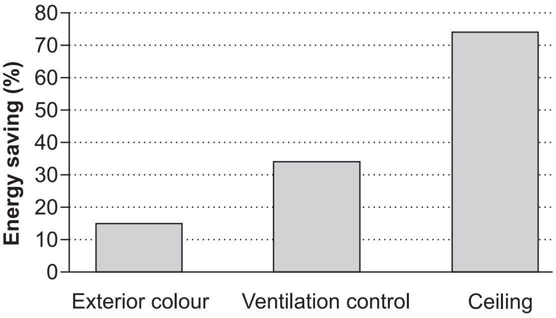

Figure 1: Comparison of measures for improving winter heating energy efficiency of formal low-cost houses

1997; Robertson and Kimsey, 1991), and for that matter, so effective at improving indoor conditions (Rorich, 2000), can be attributed to the way in which they affect the various heat transfer mechanisms at work in a house. Firstly, ceilings provide an insulating effect. Secondly, they reduce the infiltration of air to and from a room. Thirdly, they reduce the effects of stratification within a room and finally, they reduce the effect of radiative losses to a cold roof surface.

The degree to which these attributes affect the various heat transfer mechanisms have previously been determined by the authors using the *QUICK II* simulation tool (Mathews and Weggelaar, 1997). All simulations were performed for a 'typical' South African formal low-cost house (Holm et al, 1994). In performing the energy simulations, it was assumed that occupants in the houses would attempt to keep the indoor air temperature above 16°C – a lower limit identified by Eskom (Surtees, 1992) and various other parties (Wentzel, 1982). This limit was used for all the conducted simulations, and the results obtained are discussed briefly in the following section.

2. Household heat transfer mechanisms

2.1 Insulating effect

For any given air-containing space, regardless of whether it is well sealed or not, air movement occurs as a result of natural convection currents and radiation from the various indoor surfaces. In formal low-cost houses, with their brick walls and corrugated iron roof, radiation from the inner surface of the roof is usually the dominant 'force' in summer. The majority of the heat transfer to and from these houses occurs through the roof.

To combat this undesired situation, air inside the living areas of the houses must be insulated from the air directly below the roof. Installing a ceiling in a house provides that exact effect, splitting the indoor air into two separate cells and providing a barrier to the heat flow from the inside surface of the roof. In addition to the obvious physical barrier, and as a result of the air movement discussed in the previous paragraph, air layers are formed on both sides of the ceiling increasing resistance to heat flow still further.

2.2 Reduction of infiltration

Not only are the vast majority of roofing materials used in formal low-cost houses thermally and energy inefficient, but also the design and installation of the roof are such that the roof does not seal very well. As a result, infiltration causes hot outdoor air to flow into the house during summer, and air heated indoor streams out during winter. The installation of a ceiling seals the living areas off from this outdoor air, and infiltration is thereby greatly reduced.

Passive simulations performed for a typical formal low-cost house located in Pretoria predict that by limiting infiltration, summer indoor maximums could be lowered from 33.6 to 31.6°C, and winter indoor minimums could be raised from 7.9 to 11.0°C. Yet again, these comfort benefits were accompanied by an energy benefit - the maximum winter heating load required to ensure an indoor temperature of 16°C was lowered from 2.7 to 1.5 kW.

2.3 Improved stratification

Thermodynamic laws dictate that hot air always rises. This implies that in an enclosed space, the warmest air in that space will always be directly under the highest point. In a typical formal low-cost house, this warm air would be directly below the roof. The occupants of the house, who are at a lower level, would then obviously experience a lower temperature. By installing a ceiling in the house, this situation could be greatly improved, as is illustrated in Figure 2.

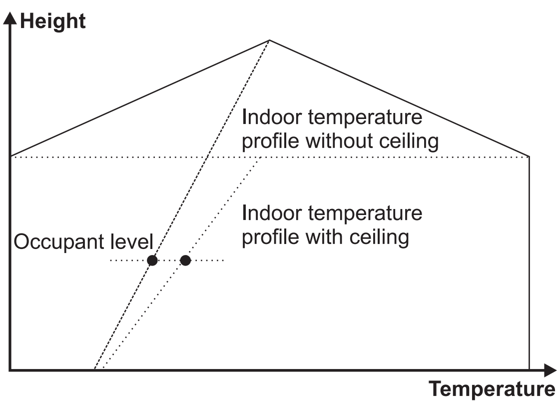

Figure 2: Simplified schematic drawing illustrating the effect of a ceiling on the indoor temperature profile

While the straight-line temperature gradients shown on the figure are perhaps not a true reflection of the real profiles, they do help to illustrate the effect in question. Passive simulations performed for a typical formal low-cost house located in Pretoria have revealed that by installing a ceiling, winter indoor temperatures at occupant level (assumed to be 1m above the ground), with no heating present in the house, could be raised from 10.3 to 12.0°C at 7 o'clock in the morning. Interestingly enough, the simulation results showed that the occupant level temperatures only increased at the colder times of the day - at those times when the occupant level temperature was already acceptable, no increases occurred.

Figure 2 also clearly shows that the installation of a ceiling decreases the volume of indoor air to be heated, which should have a substantial effect on the required winter heating loads in the house. Energy simulations performed for the typical formal low-cost house showed that the installation of a ceiling, with the accompanying improved stratification and decreased indoor volume, lowered the maximum winter heating load required to ensure an indoor temperature of 16°C from 2.7 to 1.2 kW.

2.4 Reduced influence of radiation from surrounding surfaces

Outdoor air temperatures play a prominent role in determining the temperature of a dwelling's surfaces. Surface temperatures in turn affect the air temperatures inside the dwelling, according to the following relation

$$T_{COMFORT} = 0.5 \times (T_{INDOOR} + T_{MEANRADIANT}) \quad (1)$$

where $T_{COMFORT}$ is the temperature experienced indoors, T_{INDOOR} is the actual indoor air temperature, and $T_{MEANRADIANT}$ is the average temperature of all the indoor surfaces. It is clear from this equation just how much of an effect the surface temperatures have in determining indoor occupant comfort.

Since the roof of a formal low-cost house is generally the hottest surface, it has much more of an effect in terms of radiation, than the other surfaces. The mean radiant and comfort temperatures could be greatly improved if the roof temperature could be replaced in the equation by a ceiling temperature.

As was the case for the other heat transfer mechanisms, energy simulations were also performed to determine the effect of radiation on the maximum required winter heating load. These simulations showed that by removing the effect of radiation from the roof, the maximum winter heating load required to ensure an indoor temperature of 16°C could be lowered from 2.7 to 0.6 kW.

2.5 Effect on winter energy consumption

Having separately accounted for the effect of all four heat transfer mechanisms, the four were combined, and simulations were performed for all major provincial centres nation-wide to determine the effect on winter energy consumption. The results of these simulations are presented in the following table in terms of energy consumption figures and percentage reductions in energy consumption.

Table 1: Potential reduction in annual winter heating requirements

Location	*Without ceiling (kWh)*	*With ceiling (kWh)*	*Reduction (%)*
Bloemfontein	8 138	4 194	48
Cape Town	4 115	1 153	72
Durban	3 024	548	82
East London	1 569	78	95
George	3 220	657	80
Johannesburg	5 525	2 191	60
Kimberley	5 317	2 154	59
Phalaborwa	1 511	264	83
Port Elizabeth	1 067	83	92
Pretoria	5 427	1 357	75
Upington	4 322	1 646	62

These simulation results verify the saving of 74% reported by van Wyk and Mathews (1995) for a typical formal low-cost house located in Pretoria specifically. The figures obtained for the other locations vary between 48 and 95%, but each and every one represents a massive energy saving. These results leave no doubt that enormous energy savings could be realised by installing ceilings in formal low-cost houses.

3. Preliminary research and design specifications

Having identified the effects that a ceiling has on indoor conditions as a result of the relevant heat transfer mechanisms, preliminary research was conducted to identify materials that could potentially be used as a ceiling. Once this had been completed, several specifications for the envisaged low-cost ceiling were established.

3.1 Preliminary research

To effectively compare existing ceiling materials, a measuring process that can evaluate the materials as they are used in practice was required. This stands to reason since the thermal effect provided by a ceiling is produced by the whole 'roof system'. This 'roof system' includes the roof itself, the ceiling, the air gap between the two, and the air inside the dwelling. The total thermal resistance of the complete roof system, as opposed to just the ceiling alone, provides the insulating effect.

To make provision for the evaluation of ceiling materials as part of a complete roof system, a special test facility was constructed. By providing a realistic means of material evaluation in a typical application, the effect of factors such as dust accumulation could also be investigated. The test facility was located in an underground laboratory to ensure that environmental conditions could be carefully controlled throughout the research. A schematic of the experimental set-up used is depicted in Figure 3.

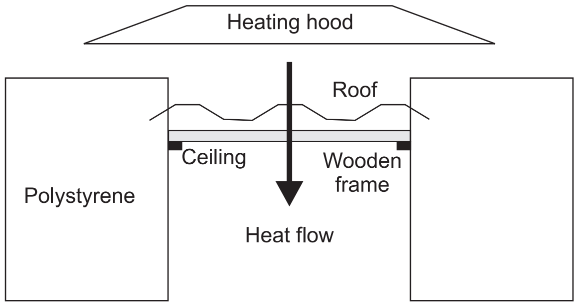

Figure 3: Schematic layout of the original experimental set-up

The structure comprised polystyrene blocks held firmly in place by an exterior steel frame. No other metal objects were used in the structure to prevent the formation of thermal bridges. Ceiling material samples were placed below a roof sample, resting on a wooden frame inside the polystyrene box. A hood containing heating elements to simulate the expected heat transfer was mounted above the roof sample.

The distance of the hood from the roof sample was made adjustable to allow for regulation of the exterior surface temperature of the roof. The distance between the roof sample and the ceiling sample was also made adjustable to allow investigation of the effect of air spaces on the total insulating effect. Surface temperatures on the outside surface of the roof and the inside surface of the ceiling were measured using thermocouples mounted flush on the surfaces. Heat flow across the roof-ceiling combination was measured with a polyurethane heat flow sensor.

During the measurement process, it was discovered that the test facility had a few shortcomings, particularly with regards the measurement of heat flow across the ceiling. To overcome these deficiencies, a second test facility was constructed. This facility made use of the guarded hotbox principle that incorporates two thermally insulated boxes, one contained within the other. The test section forms the common side of the two boxes, and the walls of both boxes are well insulated. A schematic of the experimental set-up is depicted in Figure 4.

The inside of the smaller box and the annular space between the two boxes are individually heated. The heaters in the annular space are controlled to ensure that the temperature in the space is the same as that in the small box. If this is achieved, no heat transfer will take place between the two boxes, and all of the heat supplied to the inner box will have to leave through the test section. In this case

$$Q_{MEASURED} = Q_{OUT} \tag{2}$$

where $Q_{MEASURED}$ is the amount of heat supplied to the inner box, and Q_{OUT} is the heat flow through the test section. Q_{OUT} is required to determine the sample's thermal resistance (R_c).

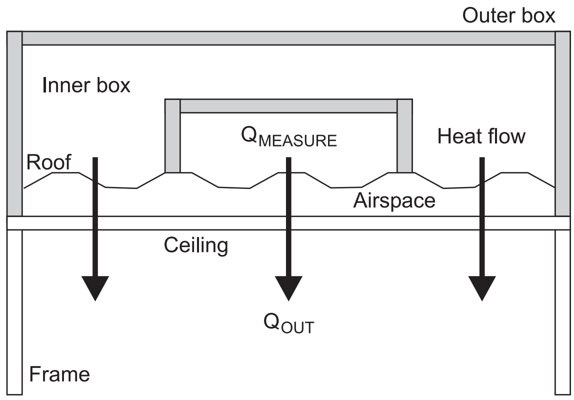

Figure 4: Schematic layout of the second experimental set-up

Theoretically, if Equation (2) holds true, all that is required to determine the thermal resistance of any material is the amount of heat supplied to the inner box ($Q_{MEASURED}$), the average temperature of the outer surface of the roof sample (T_{rf}), and the average temperature of the inner surface of the ceiling sample (T_{ce}). The resistance is then calculated by

$$R_c = \frac{T_{rf} - T_{ce}}{Q_{MEASURED}} \tag{3}$$

In practice, however, it is difficult to maintain exactly the same temperature in the inner box and the surrounding annular space. As a result, the temperatures of the inner and outer surfaces of the inner box were also measured. Together with the known conductive resistance of the inner box, these temperatures were used to calculate the heat flow across the walls of the box. This heat flow was then used to correct the measured heat supply to the inner box.

A total of seven commercial ceiling and insulating materials were evaluated and compared using the second test facility. Fibreglass insulation was one of the materials evaluated, and based upon its well-documented insulating properties, it was used as a benchmark to evaluate the other materials. The seven materials are listed in Table 2.

The thermal characteristics of ceiling and insulating products are usually listed as thermal transmittances or U-values. The U-value of a product

Table 2: Ceiling and insulating materials evaluated with the second test facility

Name	*Material*	*Outer surface*	*Inner surface*	*Thickness*
A	Glass fibre	Exposed	Aluminium foil	40 mm
B	Glass fibre	Exposed	White paper	40 mm
C	Polyester fibre	Aluminium foil	Aluminium foil	40 mm
D	Polyethylene bubblefoil	Aluminium foil	Aluminium foil	4 mm
E	Polyethylene bubblefoil	Aluminium foil	White coating	4 mm
F	Paper	Aluminium foil	Aluminium foil	0.2 mm
G	Paper	Blue coating	Aluminium foil	0.2 mm

provides information on how readily energy is transmitted through the product. For insulation purposes, the U-value of a material should be as low as possible. With reference to Figure 5, the U-value of a roof section consisting of a roof sheet and ceiling can be calculated by

$$U = \frac{1}{R_o + R_c + R_i} \quad (4)$$

where R_o is the resistance to energy flow from the outdoor air to the outer surface of the roof sheet, R_c is the resistance to energy flow from the outer surface of the roof sheet to the inner surface of the ceiling or insulation, and R_i is the resistance to energy flow from the inner surface of the ceiling or insulation to the indoor air.

It is of critical importance that the indoor and outdoor conditions be kept the same if an acceptable comparison of different materials is to be obtained, because in so doing, R_o and R_i will remain unchanged and R_c will be the only variable.

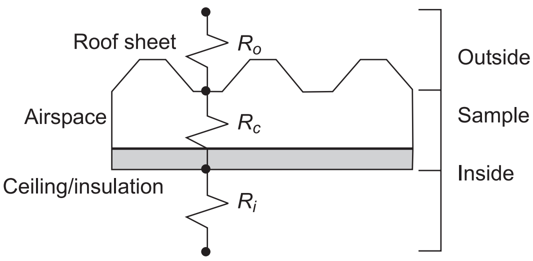

Figure 5: Section through a complete roof system

Thermal resistances (R_c) and overall heat transfer coefficients (U) were calculated for each of the seven materials evaluated, and the values obtained are displayed in Figures 6 and 7 (where the columns on the graphs are labelled according to the material list in Table 2). As expected, the fibreglass samples (A and B) were the best of the seven materials evaluated in terms of R_c values. High R_c values are a prerequisite for a good insulator, as are low U values. The U values obtained for the majority of the materials were found to be fairly similar.

One conclusion that can be drawn from these results is that from a thermal point of view, just about any material can effectively be applied as a ceiling (McGowan, 1993). While the thermal resistance of some 'roof systems' is higher than those of others, any R_c value is better than none at all. From a practical point of view this implies that good insulating materials, which are usually the more expensive, are not necessarily required, and that material costs can be cut substantially without too great a thermal penalty.

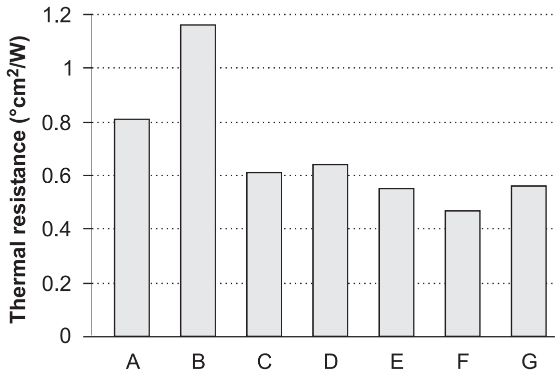

Figure 6: Comparison of the R_c values obtained for the seven products

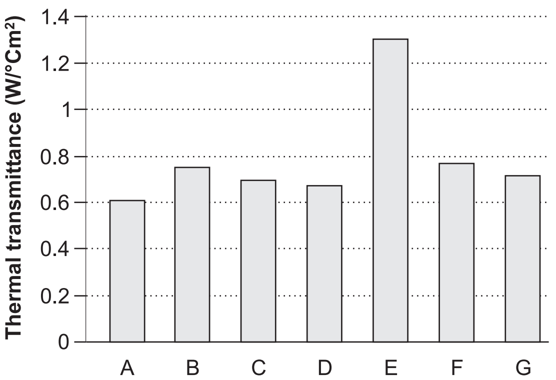

Figure 7: Comparison of the U values obtained for the seven products

3.2 Design specifications and considerations

By establishing specifications before commencing development, it can be ensured that all relevant requirements are addressed during the development process, and that no important aspects are overlooked. This is essential if the outcome is to be successful.

The specifications established for the ceiling were as follows:

- The material cost must be less than R5/m^2;
- The ceiling must be thermally efficient with a total thermal resistance > 0.5°Cm/W;
- The ceiling must be able to limit infiltration;
- The ceiling must be durable (Myers, 1996), with a life of at least 20 years;
- The ceiling must be easily installed (Do-It-Yourself - DIY);
- The ceiling must comply to all relevant building regulations (flammability, etc.); and
- The ceiling must be aesthetically acceptable to at least 80% of the target group (Tully, 1992).

Several other aspects also had to be taken into consideration. The first of these was the type of house, the construction thereof, and the layout. While a 'typical' construction and layout of formal low-cost houses has been established, this data can be effectively used for simulation purposes, not for design and development purposes. Any ceiling designed for widespread use in formal low-cost houses must be compatible with all possible constructions and layouts.

The logical first step in the design process was thus to find a ceiling type that would be suitable for all formal low-cost houses. Once this ceiling type had been identified, a suitable material could be selected for the ceiling itself. The previous section of this paper showed that most materials could effectively be used as a ceiling, since the key to providing a thermal barrier is simply to seal off the indoor environment. This made it possible to consider a wider range of materials than might have been the case.

Once a ceiling material had been selected, the exact installation method could be devised and the design process would be complete. The most important considerations at this point were the fact that the ceiling must be easy to install, manpower required for the installation must be kept to a minimum, and most of the targeted home-owners would not possess a great variety of tools to aid in the installation.

Only the results of the design process are presented in this article – no concepts or concept evaluations are included. The compliance of the proposed ceiling with the established specifications is discussed at a later stage.

4. Design results

Since the government plans to build a massive number of formal low-cost houses over the next few years (2), it might seem logical to develop a ceiling specifically with these houses in mind. Unfortunately, however, existing formal low-cost houses also need to be considered, and any ceiling type proposed for this sector should make provision for these houses as well. It follows logically that a ceiling designed for easy installation in existing houses should for all intents and purposes be just as easy to install in new houses. The proposed ceiling type is depicted in Figure 8.

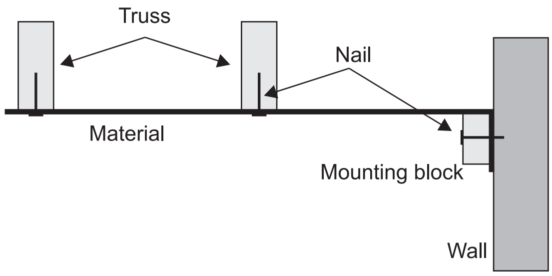

Figure 8: Proposed ceiling type

The ceiling material is simply spanned across the interior of the house, and fastened to the walls using wooden mounting blocks and nails. To prevent the ceiling from sagging, the material would also be fixed to the trusses of the house, if applicable, also using nails. If the house has trusses, the ceiling should be installed spanned parallel to the shorter walls of the house.

The ideal ceiling material for the envisaged design concept was one that could be obtained as a roll, thereby enabling the installation to be performed strip by strip. To prevent infiltration, these strips would have to overlap, and the joints could then be sealed using some form of adhesive tape. Surplus material protruding past the mounting blocks could be removed after installation to improve the aesthetic appearance.

The advantages of the proposed design concept are the low material costs, the fact that the home-owner can easily install the ceiling, the effective sealing of the indoor airspace, and greatly improved indoor aesthetics. The disadvantages are that the homeowner would have to perform some work on a ladder which might be considered dangerous, and that care must be taken to ensure proper sealing of the indoor airspace. Ensuring a sufficiently large airspace between roof and ceiling could also pose a problem.

The material that was selected for the ceiling is a reinforced aluminium foil, high-density woven polyethylene cloth laminate – Polyminium 301. It was designed specifically for use in roofing systems to limit radiant heat transfer and provide waterproofing, and it is exceptionally strong and very aesthetically pleasing. Several similar materials were considered, but the high tensile strength and puncture resistance of Polyminium 301 were the deciding factors.

The installation method selected for the ceiling was one that made use of additional fasteners placed above the wooden mounting blocks. This specific method was selected to eliminate the need for tools that would become redundant after installation, and more importantly, because it provides an effective way to pull the ceiling taught. The proposed installation method is depicted in Figure 9.

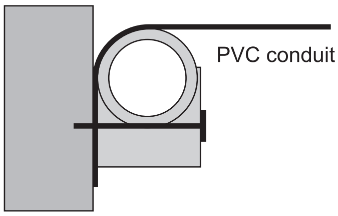

Figure 9: Proposed installation method

Various materials were considered as possible fasteners, and several methods of keeping the fasteners in place were evaluated. PVC electrical conduit was found to be the most feasible material for the required task, and the easiest way to keep these conduits in place would be to machine grooves in the mounting blocks. Once the ceiling strips have been installed, the conduits are simply forced into the grooves and the ceiling is automatically pulled taught.

5. Demonstration installation

To test the viability of the proposed ceiling, two demonstration installations were performed - one in a test house located at the CSIR, and the other in a test house located at the University of Pretoria. The first test house measured roughly 3.1 x 3.1 m^2, which although substantially smaller than most formal low-cost houses, is approximately the same size as some of the typical rooms in such a house. The second test house measured roughly 6.1 x 3.2 m^2, and the installation was performed over half of the area.

Both demonstration installations were completed by two people within 1 hour. This installation time includes the time required to cut the Polyminium, the mounting blocks and the conduits into the required lengths, but it does assume prior machining of the required grooves. Based on the demonstration installations, an estimated 5 hours would be required for an area of roughly 50 m^2, depending on the size of the individual rooms. Both demonstration installations proved to be a great success.

One aspect that was not investigated in detail in this installation is that of the quality of material of construction where the ceiling is attached to the wall. If this is poor, as is likely in many low cost houses, then the ceiling may be difficult or impossible to install. The fastening system is exposed to an axial force that wants to pull the fastener out of the

Figure 10: Installation in progress at the CSIR

Figure 11: Close-up of corner fitting and finishing at the CSIR

Figure 12: The finished product in the first test house

Figure 13: The 'before' and 'after' effect illustrated in the second test house

wall. The durability of this attachment should therefore be investigated, especially in the case of brittle materials or poor construction. It is suggested that a demonstration project be launched where this aspect is investigated in a number of houses before the development of a cost efficiency study or the development of policies. At the same time, the short-term durability of the tape joining the ceiling panels can be assessed as well as the sag over time of the ceiling, which may also vary as a function of the time of the season.

6. Cost analysis and compliance with specifications

Polyminium 301 retails at a cost of roughly R7.30/m^2, as opposed to the original specification that material cost should not exceed R5/m^2. Negotiations with the product manufacturers proved to be quite fruitful though - the material could be supplied at a cost of R5/m^2 if large enough quantities of the material were to be purchased. This agreement would ensure that the original specification was met.

For installation purposes, the typical formal low-cost house (assuming that the house can be split into four rooms of equal size) will require roughly 60 m of wooden mounting blocks, and 60 m of PVC conduit. The mounting blocks selected for use were 50 mm x 25 mm pine blocks, selected specifically for strength and aesthetic purposes. The fact that the beams are of standard size would also ensure that they would be readily available.

The chosen beams retail at R16 per 4 m length, which implies a cost of R4/m. This price is not fixed however, since the relevant suppliers would also be willing to lower their prices if large enough quantities were to be purchased. For calculation purposes, a cost of R2.50/m will be assumed. PVC electrical conduit retails at R4 per 4 m length of white conduit. This cost could also be reduced depending on volumes purchased, and for calculation purposes a cost of R0.75/m will be assumed.

It is also assumed that for a typical formal low-cost house, 80 nails will be required for the mounting blocks, and 20 nails will be required for the roof beams. Hardened steel nails are required for the mounting blocks, while regular wood nails can be used for the beams. The cost of the required nails, according to the aforementioned figures, will amount to roughly R35 per house.

Double-sided tape will be used to fix overlapping sheets to each other to prevent infiltration - one strip for each set of overlapping sheets. According to the size of a typical formal low-cost house, approximately 50 m of this tape will be required. The cost of the tape can be reduced to roughly R1.50/m by purchasing in bulk, and this amounts to a total tape cost of R75.

Using the aforementioned dimensions, the total cost per installation in a typical low-cost house is calculated as - Polyminium (R280), pine mounting blocks (R150), PVC conduit (R45), nails (R35), and double-sided tape (R75). This amounts to a total cost of R585 for a house with a floor area of 56 m^2, and thus roughly R10.50/m^2. This represents the *total installed cost* of the ceiling since no labour costs need to be added, and this figure is roughly 60% lower than for any other ceiling currently available.

The remainder of the specifications originally set for the ceiling were discussed earlier, and they are summarised in Table 3 along with the compliance of the proposed design.

The comparison clearly shows that the proposed ceiling complies very well with the specifications set at the start of the development, including the social acceptance (8). While the durability of Polyminium 301 is not known, provisional calculations performed to determine the potential for sagging revealed that the material would not sag excessively in the specified period.

To determine the energy-related impact of installing the proposed ceiling in all the electrified formal low-cost houses (26% of the total number of existing formal low-cost houses) nationwide, simulations were performed with *QUICK II*. The results of these simulations revealed that Eskom's peak demand could be lowered by as much as 242 MW.

It should be added here, however, that the above simulation assumes that all electrified formal low-cost houses use electricity for space heating. This is actually not correct, since research has indi-

Table 3: Compliance with original specifications

Aspect	*Specification*	*Compliance*
Thermal efficiency	Total R > 0.5 °Cm^2/W	Total R = 0.88 °Cm^2/W
Ceiling material cost	< R5/m^2	R5/m^2
Easy to install	4 hours	5 hours
Durability	20 years	Unknown
Building regulations	Comply	Comply
Infiltration of outdoor air	Limited	Limited
Social acceptance	80% of target group	80% +

cated that many homeowners still use their coal stoves for space heating. However, even at half the amount, 100 MW would still be significant. Eskom DSM is currently paying Energy Service Companies (ESCOs) between R2 and R3 million per MW for load shift projects, so about R200 – R300 million should be available for a ceiling project in South Africa.

At a homeowner level, the simulation results revealed that home-owners would be able to save in the region of R85 per year on winter space heating requirements, and that indoor temperatures in their homes could be reduced by up to 4°C in summer. These figures leave no doubt that the proposed ceiling could have a tremendous impact on the formal low-cost housing sector, and that the beneficiaries should be well satisfied.

7. Proposed strategy for implementation

The figures presented above suggest that Eskom would stand to benefit greatly if the proposed ceiling was to be installed in the electrified formal low-cost homes nationwide. Reducing consumption and the national peak demand is the major goal of Eskom's Residential Demand Site Management (RDSM) programme, and they require a compact and easily reproducible plan to implement a strategy for thermal and energy efficiency. The nationwide installation of the proposed low-cost ceiling could potentially satisfy their requirement.

Considering these figures, and the advantages to homeowners that were discussed earlier, it makes good economic sense for Eskom to at least investigate this option. It represents a well-focused activity, and it has a potentially large impact on thermal and energy efficiency in the country. The further development of the envisaged ceiling 'kit' and the installation thereof will provide potential business opportunities for Eskom, and several actions that are of importance to Eskom, job creation, for example, can be addressed.

8. Conclusion and recommendations

Extensive research has established that by installing a ceiling in formal low-cost houses, both the thermal and energy efficiency of the house can be greatly improved. Existing ceilings, without exception, are however too expensive to be affordable to the occupants of formal low-cost houses. In an attempt to remedy this problem, and to avert a possible energy crisis of sorts that the country might encounter, a low-cost ceiling was developed.

The first step in the development process was to find a suitable ceiling type based mainly on an easy installation process, the effective elimination of infiltration, and improved indoor aesthetics. Several design concepts were generated and evaluated using the set specifications. Once a ceiling type had been selected, a suitable material had to be found. Ten potential materials were evaluated and Polyminium 301, a reinforced aluminium foil, was found to be the most suitable.

The last remaining step in the design and development process was to devise a specific installation method, and a number of possible concepts were once again generated and evaluated. To test the viability of all of the concepts finally selected, two demonstration installations were performed on different test houses, and both were completed successfully.

The proposed ceiling was found to come very close to all the specifications set at the start of the development, cost and otherwise, and in some instances, it was found to be even better than had been hoped. Installation of the ceiling was found to be remarkably easy, and the installed cost of R10.50/m^2 is roughly 60% cheaper than for any currently available ceiling. However, as stated in Section 5, it is recommended that further trials be conducted on a number of houses to test the fastening methods of the ceiling under various other conditions prior to embarking on a national campaign.

Simulation of the installation in all electrified formal low-cost houses nationwide revealed that the national peak electricity demand could be lowered by 100 - 200 MW. In addition, homeowners would be able to save in the region of R85 per year on winter space heating requirements, and indoor temperatures could be reduced by up to 4°C in summer. These figures all represent impressive improvements, further supporting the belief that the proposed ceiling could have a tremendous impact on the formal low-cost housing sector and the country as a whole.

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