Household emission offset pilot study in the Highveld Priority Area

Report

Contract extension 4600054155 – modification 3

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Executive Summary

1. Introduction

1.1. Background

This report contains findings, conclusions and recommendations of research undertaken during the second winter after implementation of the Eskom pilot air quality offset intervention in the KwaZamokuhle settlement in Mpumalanga. Results from previous phases of the project, as well as insights from other air quality offset projects to date are also taken into considerations in the recommendations made.

The objective of the original pilot study was to evaluate the household-based air pollution offset interventions that have been identified during Eskom's pre-feasibility study and to make recommendations on the most appropriate intervention combination for scaling. The evaluation included the assessment of associated emission reductions, calculating the expected improvement in air quality, and gauging the acceptability of the interventions to households.

1.2. Objectives

The main objectives of the Modification 3 (Mod 3) project were to:

- confirm and build on the findings of the original pilot project
- decrease lead implementation and large scale roll out risks
- facilitate transition to the lead implementation phase
- attend to a few uncertainties identified during the pilot project

1.3. Scope

Swopping existing coal stoves for a LPG stove and heater appeared to be a promising option during the pilot project. For this reason we collected additional data on the 40 households who exchanged their coal stoves for LPG stoves and heaters (LPG households) during the second winter. This data collection included detailed surveys, interviews with household representatives where coal use was re-introduced and group interviews with LPG households. Similar interactions occurred with households who received the Kitchen King stove.

The contract extension request contained the following ten activities:

- Activity 1: Assess community experience of intervention after one year
- Activity 2: Second winter performance measurements of intervention variations
- Activity 3: Assess potential intervention improvement
- Activity 4: Stakeholder communication
- Activity 5: Analysis of 2016 air quality monitoring data for baseline assessment and project design document
- Activity 6: Preparation for informal housing pilot study (later removed from scope)
- Activity 7: Business process specification and data handover
- Activity 8: Compilation of project design document for large-scale roll-out in KwaZamokuhle
- Activity 9: Project management
- Activity 10: Replacement of ceilings

The specific focus on LPG in the EOP Mod3 report can be traced back to the following observations and conclusions made in earlier project phases and early Mod3 results:

- The intervention where an electricity subsidy and a basic or full retrofit was provided (and no stove swop took place) did not achieve the desired results
- One-year follow-up inspections of the Kitchen King stoves gave cause for concern about maintenance requirements and durability. This was confirmed by an inspection of a group of similar stoves that had been in use for approximately seven years on a farm near Standerton
- The feedback from the LPG households were positive, especially from the group sessions
- It has to be kept in mind that the removal of the coal stove is simultaneously the removal of the backup cooking source that a household can use in the event of power failures. The formal households already had electricity before the intervention. In a context of frequent local power interruptions, it is our view that an electricity-based intervention must include the provision of a backup energy source for the intervention to provide the households with the same or better utility compared to the pre-intervention situation. An LPG dispensation resolves this need for an alternative energy carrier and the households are free to use either electricity or LPG as main energy carrier for cooking and heating

2. Key findings and conclusions

In our view Eskom has the best chance of rolling out a successful air quality offset programme if every intervention chosen for larger scale implementation simultaneously complies with all the criteria below. An intervention should:

- **Improve ambient air quality:** This means that a net ambient air quality improvement should exist in the project scenario when compared with the baseline scenario
- **Benefit households:** Low-income households should, in addition to other benefits achieved, not pay more after the intervention for the same domestic energy utility (e.g. for cooking, space heating and water heating) than before the intervention
- **Be cost effective:** Community air quality offsets should be more economical for Eskom than the alternative (e.g. installing flue gas desulphurisation) and optimum value for the investment should be attained
- **Pose low social and safety risks:** Risks should be managed by carefully designing and implementing the project in cooperation with households and other local stakeholders
- **Be sustainable:** The positive impact brought about by the air quality offset intervention should be maintainable over the long term

Our evaluation of the piloted interventions in terms of these criteria follows below.

2.1. Air quality impact

Emissions can be reduced in three ways namely by reducing number of fuel using households, by reducing the average fuel consumption per household and by reducing the emission factor.

The mechanism of the stove-for-LPG swop is to address the number of solid fuel using households since LPG has practically a zero ambient impact in terms of the pollutants of concern ($PM_{2.5}$ and SO_2). The thermal insulation retrofit, independently of the energy carrier with which it is combined, reduces the average solid fuel consumption of households. Swopping a conventional coal stove for a Kitchen King stove does not result in a change in the volume of coal used, but does result in a change in emission factor. However, the change in emission factor will depend on the durability of the stove components and user adherence to best ignition methods.

Regardless of whether a full, basic or basic plus insulation retrofit is used, the same results are expected in the short term when solid fuel stoves are removed and replaced with LPG equipment since without a coal burning device households are not expected to burn coal. However, the full retrofit outperforms the basic and basic plus in terms of the overall thermal improvement and as such it is expected to provide the best retention rate over the long term. It is also most beneficial to households in terms of the energy required to reach and maintain thermal comfort.

In a number of cases where households had a shack or lean-to shack on the same stand as the retrofitted formal houses, they continued to use solid fuel stoves (or reverted to solid fuel stoves), which negated the impact of the removal of the stove in the formal house kitchen. Thus, in the case of households with "mixed structures", additional steps have to be taken in order to eliminate emissions from solid fuels. Currently, no readymade solution exists that fully addresses this requirement. Work is currently in process to find a thermal insulation solution for shacks. We foresee that results from this work could contribute, in combination with the solution for formal houses, to a solution for mixed structures.

Where solid fuel stoves are removed and replaced with LPG equipment (and in the absence of regression), the particulate matter emissions are avoided completely. Focussing on coal only and taking the annualised coal use of 1206 kg per household-year (control group mean, 2016) – the resulting PM emissions that can be avoided are:

- 14.48 kg of PM2.5 per year per household
- 15.57 kg of PM10 per year per household

It should be noted that addressing domestic solid fuel use alone may not result local compliance with national ambient air quality standards since there are other locally significant sources of pollution as well.

2.2. Benefits to households

Our assumption is that it cannot be expected of low-income households to fund higher energy cost to maintain their existing energy utility after the intervention. The pre-intervention utility and level of energy security therefore have to be matched, as a minimum, and preferably be improved, in the post-intervention scenario at the same or reduced cost to households.

Based on the group interviews and open-ended in-depth interviews with all intervention groups, we believe that households indeed have the same or better energy utility after the intervention at the same or reduced cost than in the pre-intervention scenario. This is mainly due to the significant benefit that the insulation renders in improving the thermal conditions inside the home. Both full and basic retrofit impacts meaningfully on people’s experience of quality of life in their homes, with better indoor thermal comfort, less dust and feeling at home in a beautified structure.

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Figure 1 shows a comparison of the differences between average indoor and ambient temperatures for houses fitted with varying degrees of insulation, measured at the time of day when the ambient temperature was the lowest; results are shown for the month of August.

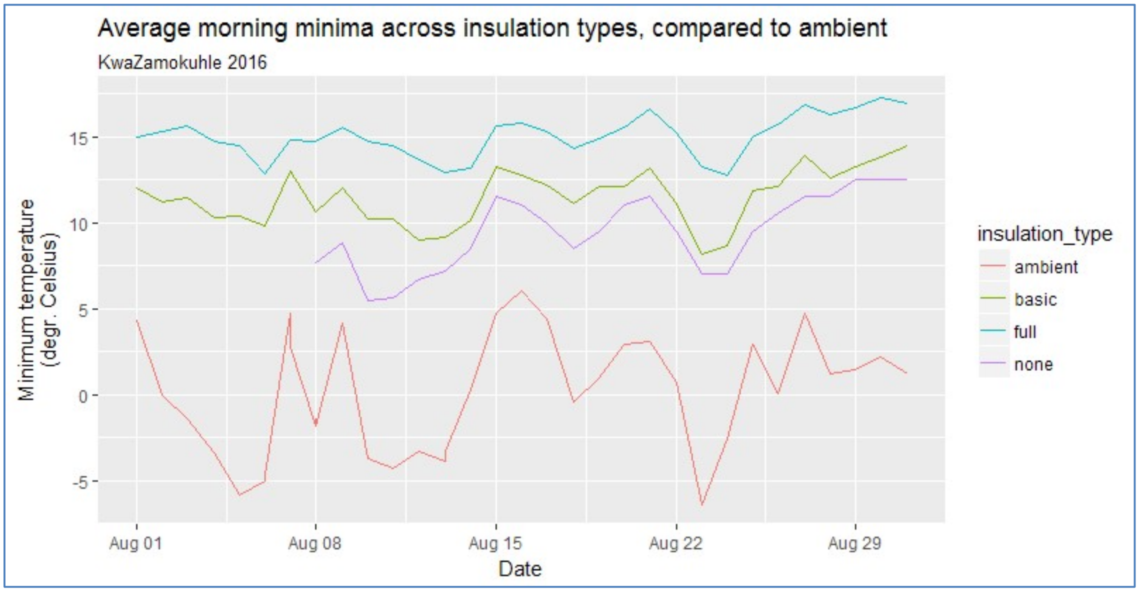

Figure 1: Average of instantaneous morning indoor minimum temperatures across insulation types and compared to ambient (period: August 2016)

There is a clear correlation between the ambient temperature and the indoor temperature. The uninsulated houses of the control group ("none") do offer some protection against the cold. The basic insulation brings about a visible improvement over the control group but the full retrofit outperforms both the uninsulated houses and the basic retrofit by far.

In terms of the energy carriers provided by the project, both LPG and the Kitchen King were positively evaluated by households. No safety issues were reported in the case of the LPG use and respondents were impressed by the speed and efficiency of cooking with their LPG stoves and that it contributes to heating the house in combination with the retrofitted insulation. The Kitchen King group enjoyed their stoves, although a number of minor design, as well as wear and tear issues were reported. The electricity subsidy group did not have to give up their current (original) coal stove to participate in the project. Thus, it was not possible to test as part of this particular assignment what the exact impact of an “electricity only” solution would be.

We conclude that all the tested intervention combinations are acceptable and desirable to end-users. The LPG stove and heater swop in combination with the full retrofit rendered the most benefits to households if all benefits are taken into consideration.

The proportion of observed time where the indoor temperature of the coldest room in the house was within the theoretical thermal comfort range (discussed below figure) for 80% of the population is given in Figure 2 for every hour of the day and for two seasons (the construction of the basic-plus took place during winter. No winter observations could therefore be obtained for this group).

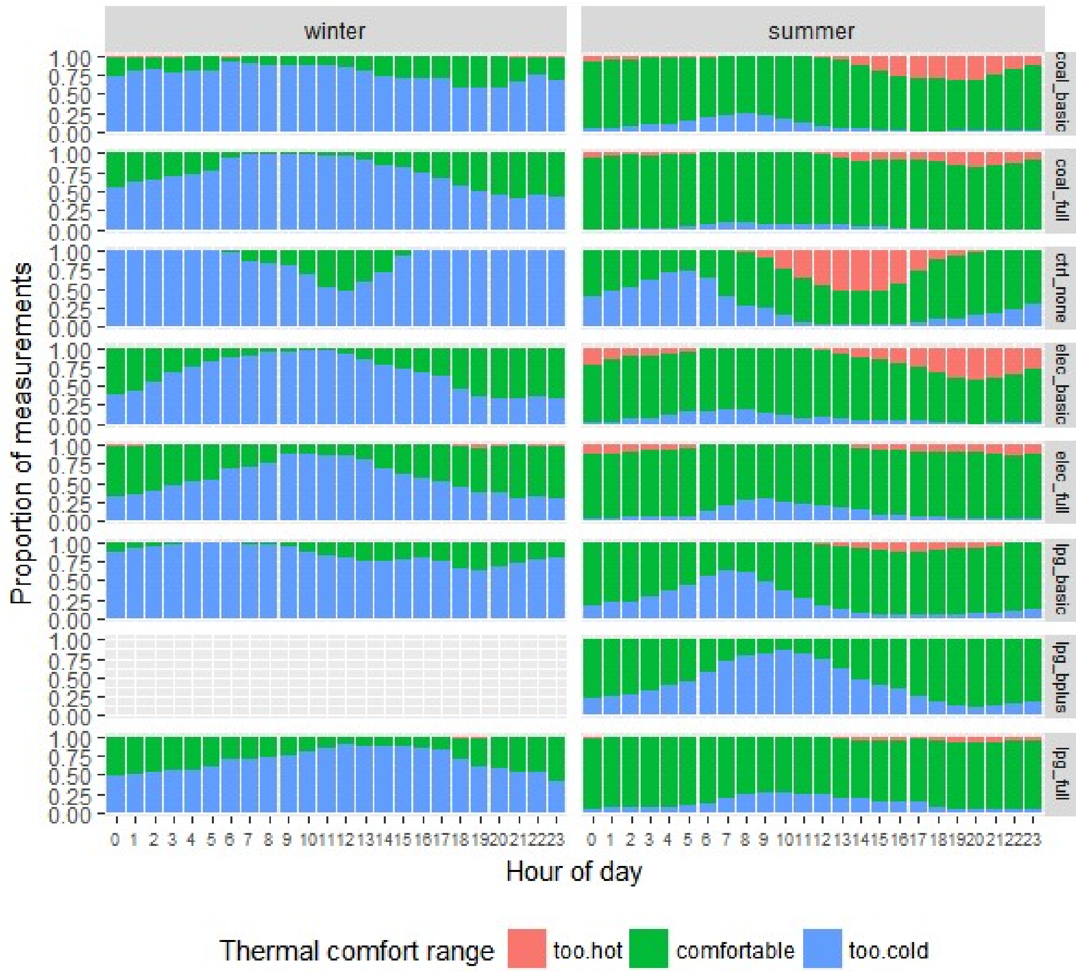

Figure 2 Proportion of time in thermal comfort per intervention type by hour of day and season

To interpret the figure above, thermal comfort must first be explained. Thermal comfort lies within a range that moves. Whether a particular indoor temperature is classified as within thermal comfort depends on

- Ambient temperature – a higher ambient temperature implies a somewhat higher indoor temperature range is required for comfort. In practice, this implies that if temperature rises quickly outside in the morning, but very slowly inside, then the inside of the house can remain relatively uncomfortably cold even as the indoor temperature rises, because the comfortable range moves up faster. Similarly, a higher indoor temperature is required on a warm afternoon (subject to an absolute indoor maximum of 29.5 °C) than during a cold morning
- Sleeping hours vs. waking hours – the calculated moving range is subject to an additional absolute subminimum, during sleeping hours, a 16.0°C lower limit for the comfort range is acceptable, versus a 17.5°C lower limit during waking hours

At any point in time, the applicable range of indoor temperature that is classified as comfortable is calculated as follows:

- For waking hours (defined as 6am to 10pm), indoor thermal comfort is achieved at 18.9°C + 0.255*ambient temperature +/- 3.5K, lower limit 17.5C, upper limit 29.5°C

- For sleeping hours (defined as 10pm to 6am), indoor thermal comfort is achieved at 18.9°C + 0.255*ambient temperature +/- 3.5K, lower limit 16.0C, upper limit 29.5°C

Analysing the temporal distribution of thermal comfort episodes through the day emphasises the differences between the intervention types. Temperatures in structures with less insulation fluctuate more. This is in the first place clear in the control group where the structure fails to provide protection against the falling ambient temperatures in the late afternoons and evenings and routinely cools down to thermally uncomfortable levels at night. At midday, the lack of insulation means that the control houses frequently overheat in summer.

Houses with coal stoves and only basic insulation (coal_basic, elec_basic) were somewhat better off than the control group with a smaller proportion of the time below thermal comfort. The fact that the episodes of overheating that did take place occurred only later in the day shows that the mid-day heat gain was also slower than in the control group, as one would expect with a more insulated structure. Judging by the time of day and the fact that the overheating episodes were absent in the LPG interventions, some of the overheating episodes later in the afternoon appear to be associated with internal heat sources such as a coal stove.

For the houses that were fitted with basic insulation plus draft-proofing and that used LPG (labelled “lpg_bplus”) we only have summer data available due to the implementation start date. These houses followed a distinctive pattern: the house warmed up slowly, meaning that it was frequently too cold at mid-morning. Later in the day, however, the proportion of time that the structure was in thermal comfort increased. In the evening and early morning these houses did not perform as well as the full retrofit houses. The slight improvement above the basic only houses can be seen in the slackened heating during the mid-day period and as such the improved resistance against overheating in the mid and late afternoon on summer days.

The houses that received a full retrofit had fewer cold episodes overall because they maintained higher temperatures during the night. Practically no overheating took place in the middle of the day. However, where coal was used, a few episodes of overheating did occur in the afternoons. An interesting feature of the full retrofit houses is that periods of indoor temperatures below thermal comfort occurred more frequently in the middle of the day than in the evenings. This can be attributed to the slow heat gain of these structures. It also relates to the formula used in calculation of thermal comfort because thermal comfort is calculated as a function of ambient temperature (which rises rapidly through the course of the morning).

Compared to the control group the interventions brought about a change in the diurnal thermal pattern. In winter the pattern shifted from being too cold all the time, except sometimes during the middle of the day, to having cooler middays (sometimes uncomfortably so) but more thermal comfort in the evenings and early mornings (in the case of the full retrofit that is more successful in retaining heat). In summer the pattern changed from being comfortable for a fair proportion of the time with frequent overheating in the afternoon and being too cold for a fair proportion of the early mornings, to a situation where there is practically no overheating and the cold episodes occur slightly later in the day (when they do occur) for the LPG basic and LPG basic+ group. The LPG full intervention was particularly successful in summer with very little overheating and few cold episodes in the late morning. The intervention groups where coal was still in use performed the best of all in winter but did experience overheating on some summer evenings.

To obtain an estimate of the expected performance of the intervention groups over a whole year a predictive model was developed. This model predicts the indoor temperature of a typical house of each intervention group, based on the ambient temperatures of the year 2016. The model was trained on observations collected between August and November 2016. A variety of prediction algorithms were tested. The final prediction was done using a multivariate generalised liner model.

We used the results to calculate the number of degree-hours outside thermal comfort for each of the intervention groups, where 1 degree-hour (°C.h) is equivalent to 1 hour at 1 degree Celsius away from thermal comfort (whether above or below). The results are displayed in Table 1 below:

Table 1 Degree-hours outside and within thermal comfort (tc) as estimated with the generalised linear models (GLMs) for all intervention types

Intervention Type	Total °C.h not in tc	°C.h under	Hrs under	Avg °C under	n days under	°C.h over	Hrs over	Avg °C over	n days over	Hrs in tc	n days in tc
control_none	16383	15516	4840	3,2	202	867	465	1,9	19	3411	142
lpg_basic	15048	14671	3826	3,8	159	376	330	1,1	14	4560	190
coal_basic	11777	11520	4228	2,7	176	257	241	1,1	10	4247	177
coal_full	11347	11298	3481	3,2	145	49	90	0,5	4	5146	214
elec_basic	9417	8963	3394	2,6	141	455	442	1	18	4881	203
elec_full	3989	3897	2504	1,6	104	92	90	1	4	6122	255
lpg_full	2912	2822	2407	1,2	100	91	94	1	4	6215	259

The typical control household is predicted to spend a total of 15516 degree-hours below thermal comfort in 2016. This, however, occurred during only 4840 hours, equivalent to 202 days constantly at 3.21 °C below the lower limit of the thermal comfort temperature range. The predicted difference in total degree-hours between the control group (16383) and the lpg_basic (15048) group is surprisingly small.

Next came the coal_basic households who would have spent 176 days constantly too cold at at least 2.72 °C below thermal comfort. This is 26 fewer days compared to the control group at roughly 0.5 °C warmer. In total, however, the coal_basic households would have spent 35 days more in thermal comfort than the control group, as the latter spent an additional 19 days overheating at at least 1.86 °C above the thermal comfort range's upper limit, while the coal_basic households would have spent only 10 days at 1.07 °C above thermal comfort.

The order of the coal_full and elec_basic is surprising as the general pattern is that full retrofit performs better than basic retrofit. The fact that both these groups continue to use coal may mean that the heat source in the elec_basic group plays a more important role than that of the insulation.

The elec_full and lpg_full households fared the best, spending only 104 and 100 days respectively below thermal comfort and each only four days above, resulting in a total of 255 days constantly within the thermal comfort range for elec_full and 259 days for lpg_full.

Figure 3 below shows the degree-hours below (left) and above (right) the thermal comfort range translated to cumulative days and average degrees from thermal comfort. Although there is variation between individual households and the results presented above are modelled, the magnitude of the results and their relative order do give an indication of how a large group of each intervention can be expected to perform, on average, over the course of a typical year.

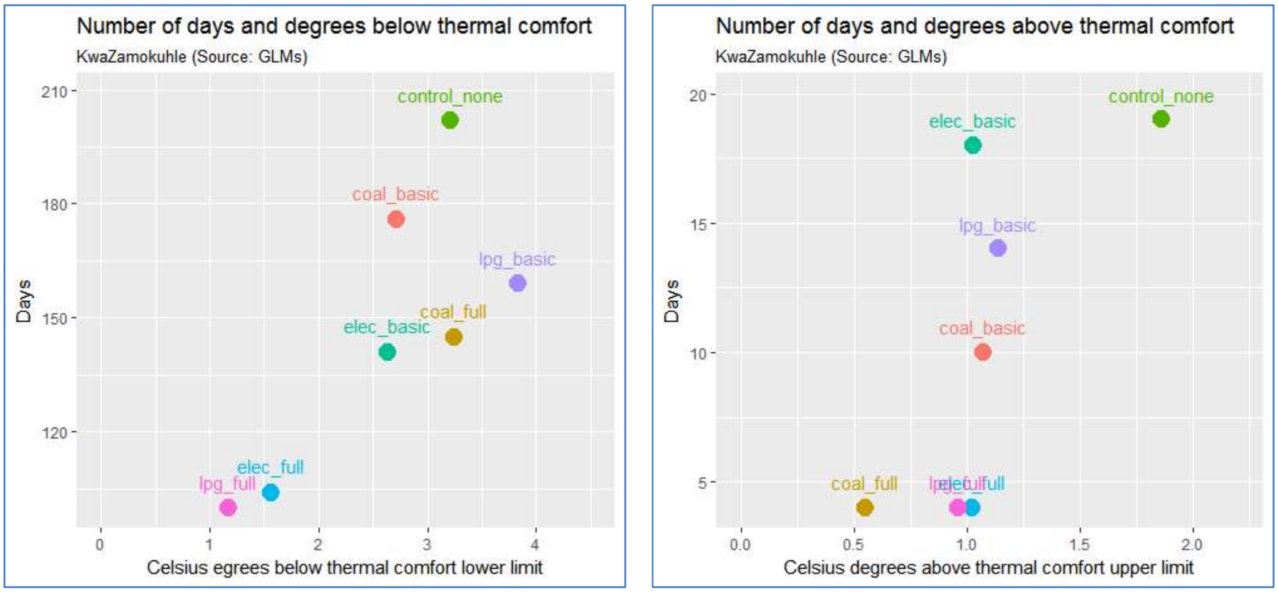

Figure 3 Degree-hours below and above thermal comfort as estimated with the generalised linear models (GLMs) and translated to y days at x degrees from thermal comfort

2.3. Cost effectiveness

One approach towards measuring the value for the industry investment is to express the cost as Rand per kilogramme of reduction in coal use (also R/PM2.5 and/or PM10 removed). The optimum investment has to be the least cost investment that also complies with all other criteria.

A basic plus retrofit and stove swop cost approximately 40% less than a full retrofit and stove swop. The cost included in this calculation includes the retrofit bill of materials (assuming SPF rather than EPS) and labour for a non-extended RDP dwelling (assuming an implementer mark-up), LPG starter pack and LPG training. The cost excludes potential electric work, certificate of compliance and local management unit costs.

The cost estimate is not shown here, considering that this document may be published during the tender process for implementation activity. The cost estimate will however be made available to the client.

An illustrative calculation could be made as follows: if a full retrofit and stove swop cost approximately R30k-R50k and it removes 15 kilogram of PM 2.5 annually for 10 years (100% retention) it is in the region of R200-R333/ kg PM2.5 removed.

A basic retrofit and stove swop will be a lower cost to industry if the retention rate is high enough. However, we cannot at this stage accurately estimate the retention rate and we expect the retention rate for the full retrofit to be higher, although this premise still has to be tested. Furthermore, the full retrofit has larger benefits to households and as such complies better with the second criterion mentioned, namely, benefits to households.

2.4. Social risk and safety

The project was executed in close cooperation with households and other local stakeholders and no evident social risks emerged.

No accidents or gas leaks had been recorded after the second winter of LPG use. It is clear that project participants understand how to use LPG and that it is understood that children should not use LPG

An investigation by Eskom personnel into the safety aspects of LPG heater use showed that the impact on indoor air quality is acceptable. Particulate matter concentrations did not seem to be affected by LPG heater use, and CO and NO2 remained within acceptable levels

The SPF ceiling system (including gypsum ceiling and intumescent paint on the underside of the SPF, the SPF being sprayed onto the underside of the corrugated iron roof) was tested for flame spread as prescribed by the SANS 428 protocol, using the test specifications as contained in SANS 10177-10:2007. A B1 certification was obtained, implying that no flame spread occurred

EPS is a non-flammable material and is mounted on the outside of the house. In addition, the EPS cladding is covered by 20mm thick non-flammable cementitious plaster on the outside. Fire spread tests were not deemed necessary in this regard

SPF wall cladding is covered by 20mm thick non-flammable cementitious plaster on the outside. Fire spread tests were not performed. We recommend that this aspect should be further investigated.

2.5. Sustainability

In our opinion the positive impact brought about by the air quality offset intervention will have the best chance of being maintainable over the long term if the work and material are of high quality and durable over the long term, there is a sense of ownership of the programme in the community and amongst end-users so that project participants permanently adapt the new usage pattern and repair any wear and tear that takes place. In other words, participants should not decide to, for any reason, regress back to coal or wood as energy carrier for cooking and space heating any time of the year. The formation of new households that do not use the interventions plays an important role in continued coal use.

2.5.1. Ownership (endorsement and capability to maintain)

There are few indications that residents take ownership of the improvements, except in the group interviews, where a stronger sense of ownership manifested.

Almost all residents are positive, they find the improvements acceptable to desirable. Ceilings are highly appreciated in spite of the complaints about some technical aspects of the EPS ceilings. In the perception of the participants, the improvement in indoor temperature is attributed to the ceiling and not to the wall cladding. There is no marked difference in the enthusiasm of houses with basic retrofit and those with full retrofit. There is a lot of enthusiasm for both LPG and the Kitchen King, but even more for LPG than for the Kitchen King. The insulation increases the sense of the house as "a place to feel at home", which is a deep need in these communities. People commented on how beautiful the ceilings make their houses. It has gone a long way to turn the house into a home.

Maintenance will be needed of the improvements made to the houses. From the interviews it seems as if few households indicate that they can fix problems with the ceilings themselves in the way that one respondent put it: "The ceiling was peeling off on the sides but that is something that we managed to fix ourselves. My husband went to buy glue and fixed it."

However, it should be noted that using an SPF ceiling system - rather than EPS - is expected to decrease the need for maintenance.

2.5.2. Stove components

After one year there are already a number of complaints about the Kitchen King. There is a variety of small problems and the most fundamental is uncertainty about how durable it will be.

The results of inspection of the Kitchen King stoves are shown in Table 2. Slightly more than a third (38%) of households experienced no problems with the Kitchen King. The most common problems experienced were damage to the water seal (32%) and cracks in the body of the stove (24%).

Table 2: Problems with the Kitchen King

Problems with the Kitchen King	% Yes	% No
Water seal damaged	32	68
Other specify	3	97
None of the problems on the list	38	62
Kitchen King door not closing properly	3	97
Indoor crack or leak on chimney pipe	0	100
Cracks in body of Kitchen King	24	76
Ceiling molten or burnt where chimney passes through ceiling	6	94
Body of Kitchen King burnt through or cracked	12	88
Barrier between coal burning chamber and smoke burning chamber damaged or broken through	9	91

There are fewer complaints regarding the LPG stove than with the ceilings or Kitchen King. It is mostly about basic things such as LPG availability, cost differences between LPG suppliers, fear that it can be dangerous and the oven.

In the interviews respondents mentioned mostly positive aspects of LPG for example that it is cheaper and quicker than coal and more reliable than electricity. Some respondents did complain that LPG is not always easily available and that there are price differences between suppliers.

2.5.3. Insulation retrofit component

The inspection of EPS ceilings revealed a variety of problems with only 23% of inspected ceilings that had no problems at all. The problem reported most frequently was that the ceiling boards have moved and left open holes (36%) while water stains where the second most frequently observed problem (34% badly stained). Cornices coming loose from wall or ceiling were observed in 28% of cases.

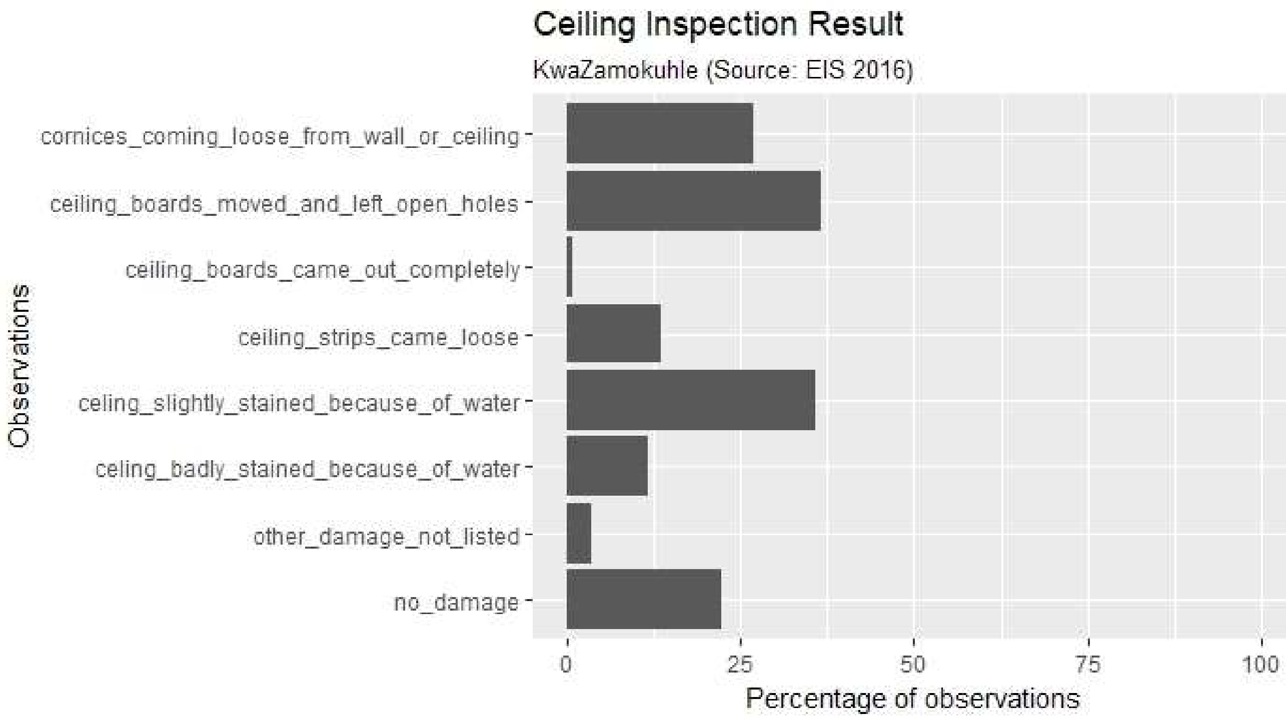

Figure 4: Problems experienced with ceilings

The wall insulation of the houses that received a full retrofit was also inspected. More than half (52%) of houses had no damage to the wall insulation. In 19% of cases the outside insulation or plaster was slightly damaged and in 19% of cases the dark paint of the north-facing wall was slightly damaged. Seven percent of the structures inspected had serious damage to the outside insulation or plaster.

Damages related to full retrofit	% Yes	% No
Problem with draft proofing	2	98
No damage	52	48
Damage to Trombe panel: slightly damaged	0	100
Damage to Trombe panel: badly damaged	0	100
Damage to outside insulation or plaster: slightly damaged	19	81
Damage to outside insulation or plaster: badly damaged	7	93
Damage to dark paint of north facing wall	19	81

2.5.4. Regression back to solid fuel

The most important factor for the few LPG households who reverted back to coal use seems to be the existence of a non-insulated structure used by the same household. Other factors may include the need for more extreme heat by some households (which cannot be affordably delivered by LPG), the need to buy in small quantities and household changes (new household formation, new occupants). The household who spent their evenings in the shack with the coal stove for heat (and slept in the main house) said that the house was warm enough to sleep in. Technical problems with the LPG stove were not mentioned. People were very positive about the LPG stove and nobody wanted the coal stove back in the house. The insulating ceilings were kept intact by all households.

After the interviews with the seven LPG households that used coal in some way, 24 LPG households were revisited in March 2017 in order to test the hypothesis that adjacent or proximate informal structures play an important role in the reintroduction of coal use. Of the households who did not have any informal structures, not one had reintroduced coal use. On the other hand, of the six houses that did have informal structures, four had coal stoves. Further visits and interviews took place to understand the regression phenomena. The following observations can be made:

- 18 of the 24 LPG households that were visited had no shacks or uninsulated extensions and none had coal stoves
- The remaining 6 had extended-structures and 4 of them had coal stoves
- Subsequent interviews with 37 LPG using households showed that 8/37 (22%) had coal stoves but only 7 reportedly used it
- The coal stoves were typically situated in a shack or non-insulated extension
- Parallel use or reintroduction of a solid fuel stove in LPG houses occurred in non-insulated informal extensions to RDP houses

Although this is a small sample there is a statistically significant association between having a mixed structure and fall-back to coal (p-value for Fisher's exact test is 0.0014). It makes sense for households who also occupy an uninsulated structure to heat that area in winter – possibly moving your entire kitchen activity there for at least the winter, as heating inside the insulated structure is less of a requirement than before insulation.

3. Key recommendations

Recommendations are made about the combination of interventions to be implemented and about large scale implementation.

3.1. Recommendations about the combination of interventions

Considering all relevant results and evaluating it against the offset project criteria mentioned we recommend that Eskom implement the following combination of interventions:

- Do a stove swop
- Install a full retrofit
- Provide quality LPG equipment

3.1.1. Do a stove swop

We recommend the total removal of the existing solid fuel stoves for the large-scale offset implementation. Where solid fuel burning stoves that were in active use are removed from households, a reduction in PM_{10} and $PM_{2.5}$ emissions is guaranteed except if the household acquires another solid fuel burning stove. Approximately a quarter of LPG households re-introduced solid fuel, but not in the insulated main house. In 6 of the 7 interviewed cases, the solid fuel use was re-introduced in a freestanding or lean-to informal structure and not to the main house. The one exception occurred where the owner of a RDP-only house passed away and the family moved - the new occupant did not have LPG equipment and thus installed a coal stove.

3.1.2. Do the full retrofit

We recommend installing the full retrofit because of a substantial improvement in thermal comfort expressed both as the proportion of time spent in thermal comfort and the absolute minimum and maximum temperature difference at the coldest time of a winter day or the hottest part of a summer day. At 5am in winter, the houses where a full retrofit was installed were approximately 6°C warmer than the control houses. Importantly, the full retrofit is best at improving both how long the house is too cold or too hot (decreased duration of thermal discomfort), and by how many degrees the house is too cold or too hot (decreased depth of thermal discomfort).

Although the full retrofit initially poses a higher cost to the project implementer than basic retrofit, it is financially advantageous for the low-income households that get the long-term benefit of reduced energy needed to attain thermal comfort. The full retrofit performs better thermally than the basic retrofit and as such it enables households to achieve similar and better thermal utility post-intervention without incurring increased cost. Thus, in terms of the criteria we expect the full retrofit to perform better in terms of "benefits to households" and "sustainability".

The ceiling that was installed as part of the intervention makes it difficult to install a new stove since there is no hole for the chimney. This presents a barrier to reintroduction of solid fuel use.

A full retrofit alone without a stove swop is at best an interim step, but actually a lost opportunity. The introduction of the retrofit intervention creates a “window of opportunity” to negotiate a stove swop with households. It is most likely that project participants will take what they had immediately before the intervention as reference point for comparison to their new situation and as such the full retrofit with a stove swop and heater will have the best chance to be positively evaluated.

3.1.3. Provide quality LPG equipment

We recommend a stove swop with an SABS approved LPG 4 plate stove with oven and an LPG heater for the large scale roll-out. The results from the follow-up interviews showed that safety concerns were addressed successfully.

3.1.4. Other observations

An electrical stove swop intervention has not yet been evaluated or piloted. These processes should be expedited should Eskom management prefer such an intervention. The implications of this approach for the additionality of the interventions need to be considered. We strongly recommend that any new intervention option be tested thoroughly and that end-user inputs, requirements and concerns be adequately addressed before any large-scale intervention starts. A planned electrical stove swop intervention should also be evaluated in terms of all the above-mentioned criteria.

3.2. Recommendations for large scale roll-out

The pilot and lead implementations have been structured to improve the understanding of the air quality offset process and to reduce the risk for the large-scale rollout. In the subsections below we provide a number of key factors that Eskom should consider in the roll-out of the large-scale community air quality offset programme.

We recommend that Eskom:

- Apply a phased approach
- Advance policy development

- Attend to critical success factors
- Anticipate strategic effects
- Address unanswered questions

These recommendations are summarised in the subsections below.

3.2.1. Apply a phased approach
Household-based air quality offset interventions are still in a development phase. Various aspects need further development and should be factored into the lead implementation design. The retrofit without a stove swop is the intervention that has been tested on the largest scale (by Sasol in Kwadela). The combination of insulation with a stove swop has been tested on a smaller scale during the pilot phase of the current Eskom project.

It is of paramount importance that further development of intervention options should take place in a programme of activities that follows a phased approach moving from pre-feasibility studies, through feasibility testing, to piloting and eventually to large scale roll-out and long-term maintenance. This should be done especially with a view to communities where household solid fuel burning is not the main source of air pollution impact or in cases where solid fuel use takes place in informal houses where the current intervention options cannot be implemented.

A formal air quality offset funnel must be developed and the likes of Eskom and Sasol can work together in a symbiotic relationship to eliminate duplication and to manage the development cycles.

3.2.2. Advance policy development
Further development of the national policy framework for air quality offsets is required to provide certainty over time to all stakeholders. This includes the development of an air quality accounting standard and associated methodologies. Eskom should actively participate in the development of this framework.

3.2.3. Attend to critical success factors
The following could be considered critical success factors to maximise the chances of a successful air quality offset programme:

- Community and household interaction
- Interaction with licencing authority
- Legal aspects
- Utilising existing expertise and developing new suppliers
- Quality assurance and quality control
- Risk management
- Programme management
- A well-defined decision making process
- Long term maintenance of the intervention
- A Programme of Activity (PoA) approach
- Determine the risk of fire if SPF is used

We discuss these factors in the paragraphs below:

3.2.3.1. Community and household interaction

The importance of having thorough interaction with the local community should not be underestimated. Expectation management, consistent messages, local presence and public sessions are examples of very important aspects to be managed professionally. The interaction and contracting of individual households to participate in the project is of particular importance and great care should be taken to do this properly. In other words, all stakeholders should understand and acknowledge that the interaction with households is an indispensable part of the programme.

3.2.3.2. Interaction with licensing authorities

The interactions with the licencing authorities are critical to the success of the air quality offset programme. The formal acceptance by the regulatory authorities of project design, monitoring plan and performance metrics that are specified in a PDD (project design document) can help to manage risks. Just as all the other stakeholders, the regulating authorities also need to grow in their understanding of the complexities and challenges involved in rolling out a community air quality offset programme. This is necessary in order to find an appropriate balance between the urgency to take the programme to scale and the time it takes to do this responsibly.

3.2.3.3. Legal aspects

The AQ offset field is still fairly immature and legal aspects are in process of development. The recommended approach in such a dispensation is to follow best available practice in related fields. During the pre-feasibility phase the legal review recommended that in the absence of specific guidance, air quality offsets projects should be structured similar to greenhouse gas offset projects such as those undertaken under the Clean Development Mechanism of the Kyoto Protocol, of which South Africa is a signatory. The *Air Pollution Impacts Protocol* and the methodologies developed under the feasibility phase of this project, as well as the PDD developed for the current phase, is an attempt at such an alignment.

3.2.3.4. Utilising expertise and experience and developing new suppliers

It is important for Eskom to follow a two-pronged approach with the appointment of implementation contractors i.e. ensure alignment with SDL policies together with ensuring appropriate expertise and experience to develop/mentor the implementers.

3.2.3.5. Quality assurance and control

Special attention to both quality assurance and quality control is required. We recommend that appropriate business processes be put in place to manage these aspects.

3.2.3.6. Risk management

Formal risk identification and mitigation/avoidance strategies must be formulated and included in the programme and project plans.

3.2.3.7. Programme management

Well-developed programme management systems together with professional experienced staff on both the Eskom and contractor's sides are essential for success.

In order to reduce transaction costs in CDM and expand the mechanism's applicability to micro project activities, the CDM Executive Board decided to launch the Programme of Activities modality.

One of the main ideas was to streamline the registration and verification of stand-alone CDM projects and by doing so to cut on transaction costs. In a scenario where a particular intervention is duplicated in several different communities, a PoA approachshould be considered.

3.2.3.8. Decision making

Due to the unknown/new/changing aspects of this AQ offsets programme, Eskom needs to have a well-defined decision making process with fast cycle times from request/issue to decision.

3.2.3.9. Long term maintenance of intervention impact

The importance of the effective long-term maintenance of intervention impact can be seen by looking at impact reduction to 50% over time, for different illustrative impact maintenance rates:

- With an impact maintenance rate of 97,5% p.a., 50% of the intervention impact will remain after 28 years
- With an impact maintenance rate of 95% p.a., 50% of the intervention impact will remain after 14 years
- With an impact maintenance rate of 90% p.a., 50% of the interventions will remain after only 7 years

Long term impact maintenance depends on mainly two factors: the robustness of the technical intervention and the proper corrective measures in case an intervention is not maintained or used, e.g. by new household formation, wear and tear, LPG that is not available, or other events.

Good progress has been made to optimise the robustness of the technical intervention, as discussed in this report.

To ensure that the proper corrective measures in case an intervention is not maintained or used, a long term strategy for the maintenance of interventions must be developed with the households. This strategy should include elements such as an education programme, a local energy centre and institutional development (see Appendix 3: Institutional development and the long term maintenance of interventions).

The onus is on Eskom to protect their investment in the communities and to determine what the different role players can contribute to the long-term maintenance of the interventions. Nova could investigate and experiment with the institutional innovation that is needed to optimise the role of each role player. A local "energy centre" in each community may facilitate Eskom continued involvement.

3.2.3.10. Determine the risk of fire if SPF is used

There is need to obtain an expert opinion about the safety of the SPF materials in the context of the RDP houses in the case of fire, e.g. would the 20mm thick non-flammable cementitious plaster on the outside crack when heated? What will happen if the plaster is not 100% intact due to wear and tear? Fire spread tests may have to be performed in situ. Nova's consultation with industry experts revealed that, currently, there are no regulatory requirements regarding fire performance of external thermal insulated composite systems. It would be beneficial to Eskom to investigate the fire performance of the current external insulation design despite regulation not requiring it in conjunction with a fire expert.

3.2.4. Anticipate strategic effects

Community air quality offset projects are particularly complex not only because of the technical complexities involved in measuring and monitoring air quality, but also because of the number of diverse stakeholders involved and the intimate nature of household level interventions. We recommend that Eskom consciously endeavour to anticipate the effects of decisions and communications. To give an example, a decision to move towards an electricity only intervention would have to be tested in use with households. This has implications for the timelines for scaling the project, since it can only be responsibly scaled if benefits to end-users have been confirmed and end-users have indicated their satisfaction with the new artefact and usage pattern. Similarly, communicating to local and national stakeholders that households in affected would receive basic retrofits even if such households are not solid fuel users will have cost-benefit implication.

3.2.5. Address unanswered questions

There are some unanswered questions that should be addressed in order to optimise the roll-out of the stove swop and full retrofit intervention. The winters of 2017 and 2018 could be used to investigate these remaining questions:

- How does a full retrofit with SPF and LPG perform during the winter?
- How effective and sustainable is the SPF ceiling solution in the longer term?
- How do households who own neither a solid fuel stove nor a LPG stove cope during short and longer power outages?
- How important is the existence of lean-to shacks or mixed structures in a larger sample in terms of potential reversion to coal use?
- How can households and communities be influenced to actively discourage solid fuel use and waste burning?

4. TOR questions and answers summarised

The EOP Mod3 contract extension request and the subsequent proposal by NWU contained a series of questions to be answered during the execution of the work. The questions and answers can be summarised as follows:

	TOR questions	Answer and/or recommendation
1	Which retrofit combination should be used for the large-scale roll-out?	The full retrofit combination.
2	What is a suitable solution for the brown mark staining of the EPS ceilings?	An SPF ceiling system including a gypsum ceiling and intumescent paint, which passed applicable SANS testing.
3	Is the LPG household energy cost the same or lower than before the intervention?	Lower and/or similar. It is reported as lower by the households in individual and group session feedback. There is no indication in the household survey reports that it was more expensive to maintain pre-intervention utility. However, the exact pattern of space heating utility changes, since a coal stove provides intensive heat for the peak burning period whereas the full retrofit leads to overall thermal improvement, as well as the ability to heat the house to thermal comfort level with less energy. A few households that used the LPG heaters regularly did report an increase in cost. Our interpretation when all data is considered is that the households did not pay more for the same or better utility in the post-intervention scenario.
4	Can the LPG intervention be recommended going forward?	Yes, provided that: • Certified equipment be used • Proper safety training with initial usage control and inspections • Local LPG equipment safety inspection and maintenance be developed It is further recommended that: • Supply and distribution of LPG be assessed and accordingly developed
5	What risks should be avoided/contained going forward?	• The household qualification criteria need careful consideration and clear communication • Implementation teams to be well trained and managed • Quality assurance, control and audit require focused attention • Consistent messages need to be formulated and clearly communicated to manage expectations of all relevant stakeholders • Eskom must maintain commitment to the phased approach: pressure to scale solutions should not compromise on the importance of obtaining end-user feedback throughout the process • Without the long-term maintenance of intervention impact there is a high risk that any improvement in air quality will be temporary (see 3.2.3.9 above and Appendix 3: Institutional development and the long term maintenance of interventions)

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Glossary

Abbreviation	Definition
A	Ampere (unit for electrical current)
AIT	Acceptable Indoor Temperature
Basic	A household in which an insulating ceiling was installed, and no wall insulation was installed
CDM	Clean Development Mechanism of the Kyoto Protocol
Coal-basic	A basic retrofit household whose original coal stove was replaced with a Kitchen King coal stove (other abbrev.: 'coal_basic', 'coal basic T')
Coal-full	A full retrofit household whose original coal stove was replaced with a Kitchen King coal stove (other abbrev.: 'coal_full', 'coal full T')
Elec-basic	A basic retrofit household who received an electricity subsidy in the first intervention winter (other abbrev.: 'elec_basic', 'elev basic T', 'elec basic T')
Elec-full	A full retrofit household who received an electricity subsidy in the first intervention winter (other abbrev.: 'elec_full', 'elev full T', 'elec full T')
LPG-basic	A basic retrofit household whose original coal stove was replaced with an LPG stove (other abbrev.: 'lpg-basic', 'lpg_basic', 'lpg basic', 'lpg basic T')
LPG-full	A full retrofit household whose original coal stove was replaced with an LPG stove (other abbrev.: 'lpg-full', 'lpg_full', 'lpg full', 'lpg full T')
LPG-basic-plus	An LPG-basic household who received additional draught proofing during the first week of September 2017 (other abbrev.: 'lpg_basicplus', 'lpg-basicplus', 'lpg basicplus', 'lpg basicplus T', 'LPG basic+', 'lpg_bplus')
Control-none	A control group household (who thus did not receive any form of insulation or stove swop) (other abbrev.: 'control')
CWS	Coal Weighing Survey
DES	Detailed Energy Survey
EIS	Energy Inspection Survey
EPS	Expanded Polystyrene
FBE	Free Basic Electricity
Full	A household who received an insulating ceiling and insulation on three walls (all except the north-facing wall)
GHS	General Household Survey
GPS	Global Positioning System
ID	Identification
kg	Kilogram
KK	Kitchen King (high efficiency stove)
kWh	Kilowatt hour (measurement unit for electricity energy consumed)
LPG	Liquid Petroleum Gas
LPGSASA	LPG Safety Association of South Africa
LSRG	Local Stakeholder Reference Group
LWS	LPG Weighing Survey
MSRG	Multi Stakeholder Reference Group
NWU	North West University
PDD	Project Design Document

PDME	Programme Design and Monitoring Entity
PM	Particulate matter
PoA	Programme of Activities
SA NDP	South African National Development Plan
SANS	South African National Standard
SPF	Spray Polyurethane Foam
STDEV	Standard deviation
UNFCCC	United Nations Framework Convention on Climate Change
UN SDGs	United Nations Sustainable Development Goals
V	Voltage (unit for electrical potential)
W	Watt (unit for electrical power)

Chapter 1 Introduction

1. Mod 3 objectives

The objective of the original pilot study was to evaluate the household emission offset interventions that had been identified during Eskom's pre-feasibility study and to make recommendations on the most appropriate intervention combination for scaling. The evaluation included the assessment of associated emission reductions, calculating the expected improvement in air quality, and gauging the acceptability of the interventions to households.

The most promising intervention was identified as the full retrofit combined with a LPG stove and heater, with removal of the coal stove. From the results of the pilot there was still uncertainty relating to the relative merits of the insulation options (i.e. the basic retrofit, the basic retrofit plus draft proofing or full retrofit) to be used in combination with the solid fuel stove-for-LPG swop and the role that an improved solid fuel stove may play in a niche application in future.

A modification to the EOP contract was done to utilise the winter of 2016 to investigate and test specific questions as well as probe some uncertainties.

The main objectives of the contract modification 3 were to:

- Confirm and build on the findings of the original pilot project
- Decrease the risks related to the lead implementation and large-scale rollout
- Facilitate transition to the lead implementation phase
- Attend to uncertainties identified during the pilot project

The contract modification furthermore aimed to address remaining uncertainties and challenges identified during the pilot by assessing:

- The relative performance of three levels of retrofit in combination with LPG technology
- The desirability of interventions to households over the longer term
- The thermal performance of the interventions and the energy usage of the households over a longer period
- Whether a full retrofit with occasional electric heating inhibits both coal use and LPG heater use
- The availability of a ceiling or roof insulation solution that addresses unsightly brown stains caused by roof leaks and moisture

A second round of winter surveys, household monitoring and testing of new and amended insulation interventions was required to address these remaining uncertainties.

The additional measurements, interviews and surveys required on-going interaction with the community and households. This was achieved through continued presence at KwaZamokuhle and further Local Stakeholder Reference Group meetings.

2. Mod 3 scope

The contract extension request contained ten activities. The contents of these requested activities are (practically verbatim) given below:

Activity 1: Assess community experience of intervention after one year (sustainability of interventions)

- Revisit 120 retrofitted households and the control group of 20 households in KwaZamokuhle to obtain data with regards to energy use, intervention experience and qualitative experience of the interventions through focused interviews
- Conduct focused interviews with the 40 LPG households to understand their particular experience of LPG use
- Conduct group sessions to obtain improvement/optimisation inputs from the community

Activity 2: Second winter performance measurements of intervention variations

Monitor energy use, fire cycles and indoor temperature in a sub-selection of the retrofitted households.

Activity 3: Assess potential intervention improvement

- Assess practical alternatives for LPG distribution, logistics and subsidy
- Assess alternatives relating to insulation, especially with a view to meeting the challenge posed by roof leaks and condensation in formal houses, and addressing health concerns associated with the insulation material (if valid)
- Assess the impact of adding draft proofing to 10 LPG basic houses with temperature monitoring on all 20 LPG basic houses as well as at least 10 LPG full houses
- Assess whether older Kitchen Kings stoves (after several years of use) are still effective, and obtain an indication of real life emissions
- Assess whether users of Kitchen King stoves still use the stoves in a manner that is consistent with low emissions
- Assess household experience of an intervention that combines cooking with LPG and space heating by means of electric heater, in a retrofitted environment
- Assess thermal performance in a formal household LPG environment, of three levels of insulation:
  - full retrofit
  - ceiling only intervention
  - ceiling plus draft proofing and painted wall

Activity 4: Stakeholder communication

- Conduct two meetings with the Offsets Multi-Stakeholder Reference Group (MSRG)
- Conduct three meetings with the Local Stakeholder Reference Group (LSRG)
- Maintain an on-going presence in the community and respond to community issues. Establish a formal “contact” line that participants can call and complain, comment or provide feedback

- Harmonisation of stakeholder engagements with Eskom so that there is consistent messaging

Activity 5: Analysis of 2016 air quality monitoring data for baseline assessment and project design document

Analyse the 2016 ambient air quality monitoring data provided by Eskom and the Department of Environmental Affairs (Hendrina) and the 2016 indoor air quality monitoring results from NWU together with the 2015 baseline results as input for the project design document.

Activity 6: Preparation for informal housing pilot study

The original scope of the request included an activity to conduct socio-economic surveys and interviews with a statistically representative number of informal houses in KwaZamokuhle in order to understand, inter alia, energy usage patterns, shack legality and permanency and shack structure in order to inform the design of a shack pilot study.

This requirement was removed in subsequent negotiations as it is not an extension of the earlier RDP-based activities. Sasol is currently conducting shack insulation testing.

Activity 7: Business process specification and data handover

- Develop relevant business process specifications for the implementation
- Offset preparation and offset improvement deliverables and related data are to be made available to an entity to be contracted by Eskom to complete the lead implementation activities. Allow for regular interaction and explanations

Activity 8: Compilation of project design document for large-scale roll-out in KwaZamokuhle

- The consultants are to compile the initial project design document (PDD) for the KwaZamokuhle interventions roll-out, including all aspects of stakeholder interaction, measurement, offset quantification methodology and implementation
- In preparing the initial project design, the consultant should provide for appropriate technical stakeholder interaction and support to Eskom for the validation by appropriate 3rd party

Activity 9: Project management

- The programme management function should take overall responsibility for the lead preparatory work and coordinate all related project activities. The programme management entity should ensure coordination, communication, quality delivery, project budget limit maintenance, adherence to schedules, scheduled client interaction and client request responses
- Perform project coordination between expert teams
- Administrate and participate in client progress meetings
- Provide feedback for Eskom Air Quality Offsets Steering Committee

Activity 10: Replacement of ceilings

Introduction

- Replace ceilings in 20 houses with an alternative that will be resistant to the brown staining

Chapter 2 Project activities

This chapter discusses the methods and results of the ten Mod 3 project activities.

1. Activity 1: Assess community experience of intervention after one year

1.1. Method

Community experience of the intervention after one year was assessed in three ways:

- Follow-up visits to 120 households
- Focus group discussions with four groups
- Visits to LPG households who continued to use coal including in-depth interviews and a follow-up survey

1.1.1. Follow-up visits to 120 households

All 120 households who received interventions were visited by 4 fieldworkers in August 2016, under supervision of Mrs Thembi Tsotetsi.

The fieldworkers were given three questions to ask, namely:

- What do you think of the changes to your house?
- What do you think of the LPG stove and heater / Kitchen King stove / electricity subsidy you received?
- Please give your opinion on the advantages and disadvantages of the energy or fuel you use in your house?

Responses were recorded, translated and summarised.

1.1.2. Focus-group interviews with four groups

Four focus group interviews were conducted in September and October 2016. The four groups were all recruited from households who participated in the project and comprised different energy carrier – insulation type combinations. These were:

- LPG – basic retrofit
- LPG – full retrofit
- Kitchen King – basic retrofit
- Kitchen King – full retrofit

There were 20 households in each group. One resident from each household was invited to the group discussion. About 8 people per discussion turned up. Mrs Thembi Tsotetsi acted as focus group facilitator, supported by Dr Attie van Niekerk.

Project activities

1.1.3. Visits to LPG households who continued to use coal including in-depth interviews and a follow-up survey

In the pilot, 40 households received LPG technology along with insulation retrofit and relinquished their coal stoves. During 2016 LPG consumption was measured in 29 of these households (refer to LPG Weighing survey Chapter 22.1.3). Amongst them, seven households were identified who used coal.

On 11 October 2016 Dr Attie van Niekerk and Mrs Thembi Tsotetsi conducted in-depth open ended in situ interviews with residents of six of these seven households in order to find out the reasons for reverting to coal.

After the interviews with the seven households that used coal in some way, 24 LPG households were revisited and surveyed in March 2017 in order to test the hypothesis that adjacent or proximate informal structures play an important role in the reintroduction of coal use.

1.2. Results

1.2.1. Follow-up visits to 120 households

The impressions were gained from the follow-up interviews with the 120 intervention households included:

- The general mood is positive to very positive, even where there are certain complaints about aspects of the interventions
- The ceilings are highly appreciated because of the thermal comfort and the reduction in leakages in the roof, although there are many complaints about technical aspects of the ceilings. A few mention that it keeps the dust out
- The improvement in indoor temperature is attributed to the ceiling and very seldom to the wall cladding
- There isn't any difference visible in the enthusiasm of residents whose houses have received only basic retrofit insulation and those who have received full retrofit
- Although both are seen as positive, there seems to be more enthusiasm for LPG than for the Kitchen King. The LPG stove is clean and quick, the gas lasts for a long time (in the case of cooking, not heating) and it saves electricity. There is still some fear that LPG is dangerous, and one can run out of gas
- The general feeling about the Kitchen King is positive, it is a warm stove and the warm water is convenient. There are a variety of smaller problems with one fundamental problem: some Kitchen King stoves have already developed cracks. This is important because the cracks become worse over time and the changed air flow could make the stoves less efficient in terms of emissions
- After a year (2 winters), maintenance was already required, especially for the ceilings and the Kitchen King stoves
- There are few indications that residents take ownership of the interventions, implying that individual households do not experience themselves as able to do maintenance
- There are several indications that residents are, at best, uncertain about who is responsible for maintenance

Project activities

1.2.2. Focus group interviews with four groups

After one year of experience (2 winters), in the context of a challenging LPG distribution environment the following is noted from the group discussion:

- In the group sessions households are generally positive about the interventions
- This positivity should not be over-interpreted (honeymoon phase); if interventions are affected by wear and tear over time, residents may later on take the present situation as the new point of reference and the positivity may decline; however, the positivity should be utilised as an important aspect of an eventual long term maintenance strategy
- Households have a fairly good understanding of the goal of the whole programme (improved air quality and health), they trust Eskom and Nova's intentions
- The thermal performance of the retrofit improves the house as “a place to feel at home”
- The insulation retrofit is beneficial in winter and in summer
- The LPG stove swop and insulation intervention is viewed positively by the group. The cost perspective is prominent, since the insulation decreases the requirement for heating (limiting LPG heater use). LPG is reported to displace both coal and electricity (cooking). Issues were mentioned in terms of the difficulty of obtaining LPG
- The Kitchen King was also experienced positively, with much utility derived. Specific wear and tear issues and improvements required were however noted
- The ceilings were much appreciated for their thermal benefit, the aesthetics (in absence of brown stains), avoiding droplets (condensation or leak related) from falling on clothes and furniture. However, where droplets now fall from the roof to the ceiling, this creates brown stains in some houses, and problems with the EPS ceiling are noted from the group sessions
- The wall cladding was not credited by many for the improved temperature – the ceiling was perceived as the main contributor. This is probably a perception – all insulated houses are thermally improved, and one is not aware of how much more or less comfortable a neighbours house’s inside is relative to your own in the early hours of the morning, when the wall cladding is likely to be most significant.
- While individuals mostly indicate that they do not have the money or the skills to maintain their homes, the feedback in the group sessions was that the community is able to maintain the interventions: the people who installed it are still available to maintain it, and individual households can be expected to take ownership of the maintenance responsibility.
- NOTE: If the positive group dynamic can be supported and utilised well, they group may assist individual households that do not have the capacity to maintain the interventions on their own

1.2.3. Visits to households with LPG who continued to use coal

During 2016 LPG consumption was measured in 29 out of the original 40 households who received LPG equipment. Of the 29 households, seven households were identified who used coal. In three of these seven households, the coal use is not in the original intervention household (due to new household formation; new occupants; coal use in tenant's house). There a minority of households that requires fairly extreme heat which cannot be provided affordably by LPG even in the context of a retrofitted insulation, and is provided by coal.

Project activities

1.2.3.1. Interviews with seven households

The in-depth open ended interviews conducted on 11 October 2016 with residents of six of these seven households who reverted back to coal use revealed the reported reasons why households who received an LPG stove still used coal differ for the seven houses interviewed.

The reported reasons were:

- One family (basic retrofit) moved away after the father passed away, taking the LPG equipment with them; they were not interviewed
- One family (basic retrofit) prefers LPG, but sometimes they can only afford small quantities. Since one cannot buy LPG in small quantities, they buy coal
- One family (full retrofit) still uses LPG, but the grandmother who is staying with them feels too cold in winter. She buys coal for the tenants who stay in the shack and sits with them in the evenings until she comes home to sleep
- One family (basic retrofit), who is very positive about LPG for cooking, said that the LPG cannot heat the house sufficiently in winter. They borrowed a coal stove and put it in the shack at the back of the house. In the evening the whole family sits around the coal stove. They also have a TV there. They come into the house to sleep as it is warm enough to sleep in. She continues to cook on the LPG stove - it is quicker and neater and she does not want to cook on the coal stove because it makes the pots dirty
- One family (basic retrofit) still uses LPG, but the grandmother and grandfather moved into the shack next to the house and bought a coal stove to use there
- One family (full retrofit), prefers LPG but sometimes runs out of LPG for the heater and finds it too expensive to buy more LPG for the heater
- One family (full retrofit) bought new furniture and the room where the LPG stove used to be became a living room. They had a coal stove in the shack next to the house that they used sometimes when it was cold; they now use the coal stove again for cooking as well. They do not use the LPG stove anymore as there is no place for it in the house and she does not want to put it in the shack with the coal stove, for fear of fire

1.2.3.2. Follow-up survey

The follow-up survey (March 2017, n = 24) into the role proximate informal structures in the reintroduction of coal use showed that only households with informal structures reintroduced coal use. Of the six houses that did have informal structures, four had coal stoves.

Although this is a small sample there is a statistically significant association between having a mixed structure and fall-back to coal (p-value for Fisher's exact test: 0.0014). It makes sense for households who also occupy an uninsulated structure to heat that area in winter – possibly moving your entire kitchen activity there for at least the winter, as heating inside the insulated structure is less of a requirement than before insulation.

The existence of extensions may be important: in all cases above the use of coal takes place within a non-insulated adjoining (or proximate) informal structure or room. Not one of these households wants to have a coal stove back in the house, because they feel it is too dirty. For most households there is no need, since the insulation provides sufficient thermal comfort during winter to sleep. Even individuals who do want more heat and who make fire in the non-insulated adjoining structure or room find the house warm enough to move back there to sleep.

It is difficult to assess the risk that installing LPG may not result in the desired reduction in emissions in a given household. It could not have been foreseen that a certain family would move away after the father had died, but one must expect a certain level of erosion due to people moving away. All the other motives to use coal in non-insulated extensions could potentially also be found in households that do not have such structures, but there has been no evidence that coal use takes place in the absence of a non-insulated structure or room.

One can assume that coal use is as high as before in the household formation case (where the grandmother and grandfather moved into the shack next to the house and bought a coal stove), but in some of the other cases the coal use may be lower.

To summarise, the most important enabling factor for a return to coal use seems to be the existence of a non-insulated structure on the same site as the participating household. Motivating factors may include the need for more extreme heat by some households (which cannot be affordably delivered by LPG), the need to buy in small quantities and household changes (new household formation, new occupants). People were very positive about the LPG stove and nobody wanted the coal stove back in the house. The insulating ceilings were kept intact.

1.3. Illustrative Quotes

The post-intervention experiences of households are given below by means of a selection of illustrative quotes from the reports mentioned above.

1.2.1. Quotes from the snap survey

1) Regarding insulation

The vast majority is positive about the ceilings:

- “This ceiling makes me very happy. I love it, it is white. I get warm in winter, we used to light the stove in the shack, when we come in here, it is nicely warm. We sleep well because it is warm”
- “There is a difference, it is hot, the wind does not come in like before, the dust you see… I feel happy for the ceiling because it is hot. It is warm here inside the house, it is clean”
- “On the part of the roofing, the ceiling that they installed, there are no longer leaks that would be as if it is raining in the house”

The fact that the leakage drops have stopped is hardly mentioned, but the brown stains on the ceiling are emphasised:

- “I no longer experience leakage drops, the leaks are now only on the sides”
- “It makes me very happy. There are some spots but they don’t disturb me”
- “The problem is this thing becomes dirty. It has rust, so now I have to buy paint and paint the house so it now costs me”
- “The ceiling is good, but the rust, it doesn’t let in the dust, it is warm, it’s is good, but the rust, that is all”
- “When the toilet flushes the ceiling gets rusty, but your work is beautiful”

- “Because if they have scrubbed the roofing first and painted it, look now it has rusted, I don’t know what to do to it as it is like this”
- “It gets rusty. It has droplets there on top”
- “My only complaint is with these stains here on the ceiling, yes that is what gives me troubles”

The cracks in the ceiling were also a problem:

- “This ceiling is good, it is beautiful it doesn’t have any problem just that it has cracks. It keeps us warm, it is good”
- “It is very good, the only thing is it has marks, it’s cracked, I don’t know, you see these cracks"
- “This ceiling is good, it is beautiful it doesn’t have any problem just that it has cracks"

It also opens up on the sides:

- “It pops up, it peels off here on the cornice”
- “The bad thing is sometimes the ceiling opens up there, but it is not too bad”

2) Regarding wall cladding

Only a few mentioned the wall cladding:

- “I like it because it makes the house warm; and this thing that they installed outside it makes the house tidy”

There were two complaints about the wall cladding:

- “Yes and this thing that they installed outside, they didn’t install it well. When I look at other houses, I don’t understand if it was installed by someone with no experience or not”
- “I am not satisfied with it on the outside, they didn’t do it well. If they could come back and do some touch ups there; everything is good and this ceiling as well, they should put that glue in correctly so that the wind cannot come in because it can still come in”

3) Regarding LPG the general feeling is very positive, in spite of some complications.

LPG saves electricity and lasts for a long time:

- “The good thing about gas is that is more cheaper than electricity”.
- “The stove is good because even this thing of it lasts… the gas that came with it”
- “They are very good because I even save on electricity. The stove works fine there is no problem and the gas is okay it even last a long time. About the LPG stove…wow, it is treating me well. It also helps me a lot I can save”

Project activities

People can run out of gas:

- "It is beautiful the only thing is I sometimes run out of this gas"

The gas stove is fast:

- "This stove, when I'm in a hurry and I cook on it, it is fast"
- "The LPG stove is quick when it comes to cooking. Even if I start late I will eat quickly"
- "The gas, the LPG stove and heater, wow it is very nice, I can now cook at whatever time I wish to, even when there is no electricity, I can still cook; and it cooks faster than the electricity"

You are not dependent on electricity:

- "Now I can cook even when there is no electricity. I can use the gas stove. It is treating me very well. My wish is that I keep it…."
- "The heater and the gas make me happy, and they help me a lot. Even if there is no electricity I can cook on it, if I have it because now it is finished. And when it is cold, we can sit in here and watch TV while we sit around it, the house becomes warm….."

Gas is dangerous:

- "The thing that I am scared of is the stove, because I am scared of this bottle that they did not close you see. Because I can no longer see properly with my eyes, so when they are here they light the heater for me and the stove as well, when they are here they light it because I am scared of it. Like on Saturday, they cooked on it and when they finish they close the bottle and put it in the bedroom. I don't want it to be here because this one is very mischievous"
- "The bad thing about gas is that if you were careless and not closed it properly it can cause an accident, so at all times you must be careful"
- "The bad part of gas it doesn't want you to leave it open because it is dangerous, you must be careful most of the time.it mustn't be used by kids, you must light it yourself as an adult"

The heater is appreciated but some complain it uses too much LPG, there are also other complaints:

- "The heater we no longer use it because it burns for three days and then it gets finished. It quickly runs out, the one that lasts up to three months is this one we use for cooking"
- "The LPG heater is hot"
- "It is treating me well, especially the heater, I use it a lot"
- "And the good part of it is that it makes the house to be warm and it's warmth is good because we save a lot on electricity"
- "And the heater gets really warm, it is hot. It is really hot even the windows sweat"

- "The heater is also good. It doesn't give me any problem the only thing is I sometimes run out of gas, and then I leave it when I am out of gas. I don't have money I am not working, I do not have money to buy gas"

Only one respondent said that he did not want the LPG stove:

- "I want the coal stove, this gas stove, I can't use it."

4) Regarding the Kitchen King stove

The feelings are mostly positive:

- "The stove is all right, it is hot, I also get enough hot water, but because it is in the shack, it won't be too warm like if it had been here in the house"
- "There is nothing bad. The coal is saved"

There are also a variety of smaller complaints.

Ash:

- "It is all right, but the bad part of it is that… it's dust, it's ash, it is too fine. But it is a good stove, it is hot and it is also beautiful"

It is "picky on coal":

- "I don't know if maybe it is picky on the coal or what, because when you light fire wood, it gets hot, but once you put in the coal it sometimes refuses to burn. The coal becomes 'deicoal' " (unclear)
- "The Kitchen King is treating me well, but it is picky on the coal. But I ended up understanding what kind of coal I should use in it. Even with fire wood only, it burns well"

Leaking boiler

- "It is still okay, it had leaked on the boiler, but we called Nova and Mr Mashinini came back and repaired it for us. It is still all right"
- "The change was good, just that the problem with it is the stove is leaking, the boiler is leaking "

Coal use is high:

- "That one is number one, it heats up nicely, it cooks, we bath, here in the house, it is warm, the only thing is it consumes a lot of coal. It requires a lot of coal. But it is okay"

Cracks:

- "The stove is fine, but it also has a metal that is cracked on the inside. I don't know how I can fix it or if maybe they would fix it"

- “We are happy with the Kitchen King because it does a lot for us. The water is always hot everyday, it does a lot for us, the stove is good; it’s just that it is cracked”

Diagonal grid (sieve) wears out:

- “The sieve gets worn out”
- “That sieve is worn out, that little sieve you saw it?”

Uncertainty regarding life span:

- “It only has good things. I just don’t know how long it will take but it is good”

Rust:

- “The stove gets rusty, there on top, where they have closed on the side of the stove, the water gets in that thing, I don’t know what it is they used there it didn’t close properly”

Uncertainty regarding cleaning:

- “The stove is all right, it doesn’t consume a lot of coal. The electricity gets saved…There is nothing bad about it. There is just one problem. How do we clean this stove?

There are several indications that residents are, at best, uncertain about who is responsible for maintenance:

- “It is starting to be open on the sides a little bit. If they could get more glue and put here on the sides. And also here on the chimney, when it is raining, the water gets in”
- “The stove is fine, but it also has a metal that is cracked on the inside. I don’t know how I can fix it or if maybe they would fix it”
- “The problem is this ceiling peels off like here, but they come and fix it, like here they didn’t fix it but they said they will be back”

1.2.2. Quotes from the group discussions

1) Regarding ceilings it was said that it…

- Beautifies the house:
    - “In my house I didn’t have a ceiling, but now it is beautiful now that there is a ceiling.”
- Makes the house warm:
    - “When I come in, it is warm. I love my house…”
- Prevents leaking and the formation of droplets on the roof:
    - “Now I can use white sheets, there are no droplets, there is a difference “These droplets were ruining the furniture…Now the furniture is good. This roofing was ruining a lot of things, not only clothes, they were also ruining furniture. Now it is very beautiful. There is a difference in many things”

Complaints:

- “I have a small complaint. There at home, where they have installed the ceiling, on the sides, there are some places where it is peeling off a bit.”

Project activities

2) Regarding wall insulation it was said that it makes the house warm:

- "….and this thing that they put outside, it makes my house to be very warm"

3) Regarding the Kitchen King it was said that it…

- Burns cleanly:
- "It is clean and hygienic, we no longer experience a lot of smoke"
- Warms water:
    - "On the stove there is water, it is good, the children can bath and go to school"
- Saves electricity:
    - "Electricity gets saved, in winter we were not using electricity (to cook and for warm water) because they gave us stoves, we lit those stoves. You are able to get water, you cook and the house gets warm, you won't need to go to the electricity"
- Cooks effectively with several pots:
    - "It is very nice using this stove, because it doesn't make the pots dirty, you can fill the boiler, like on Sundays, you put all your 6 pots and water everything gets done, you won't have to put in more coal. And it gets done quickly, when you go to church, you are done cooking

Complaints:

- "…please insert a stand, because there is no stand inside the oven" [This refers to an oven rack.]
- "What I am complaining about is that the sieve that we pour coal on quickly got finished. It is finished, it got finished too quickly. It is torn. It has become damaged too quickly". [This refers to the diagonal coal grid.]
- "What I noticed is that on the tap, this rubber quickly gets burnt and damaged. Then it quickly starts leaking. [This refers to the tap on the geyser.]

4) Regarding the LPG stove and heater it was said that it…

- Is in some ways better than coal:
    - "…a bag of coal does not last the whole week, you use it for only three days, you light the coal stove in the morning and in the evening. The gas on the other hand I cook on it in the morning, and in the evening, it is not like the coal, I cook the food quickly and when it is done, I switch it off and put it away" (full LPG)
- Heats up quickly:
    - "It heats up quickly. On the electric stove, it takes a long time, the stove plate must heat up and the pot is also big. But on the gas stove, you light it now, in a few minutes the water is warm and you can bath. It wasn't wasted a lot" (basic LPG)
- Is not always easily available:
    - "During winter, there was a shortage of gas at the garage. A person who would be in town would call you and say 'here are the gas cylinders, they are being offloaded' by the time you get to the garage you find that they are finished because they are only sold in one garage… we buy it for R220 at one place and R180 in other places, the prices differ. Maybe they could bring these gas bottles

closer, and it could help with the different prices… And the changing of bottles, you see now we get the red ones, if you buy with a red bottle and they give you the green one, they will never give you the red one again. If you are using the green one, you must go and buy at that same shop"

- Provides enough heat:
  - "It is warm. The gas heater we only use it when it is extremely cold. When I cook with this stove, I don't use the heater because it is warm here in the house" (basic LPG)
- Is more reliable than electricity:
  - "There have been some days whereby there was no electricity, we could cook, we could bath and we could do everything. If we didn't have that gas stove what were we going to do?"

5) Regarding maintenance of ceilings it was said that households can generally fix it themselves:

- "The ceiling was peeling off on the sides but that is something that we managed to fix ourselves. My husband went to buy glue and fixed it."

1.3. The following trends were noted overall:

- Almost all residents are positive; they find the improvements acceptable and desirable
- Ceilings are highly appreciated despite the complaints about technical aspects
- In the perception of the participants, the improvement in indoor temperature is attributed to the ceiling and not to the wall cladding
- There is no marked difference in the enthusiasm of houses with basic retrofit and those with full retrofit
- There is a lot of enthusiasm for both LPG and the Kitchen King, but even more for LPG than for the Kitchen King
- Savings that could be realised as a result of having the electricity voucher was used not only to fulfil in the demand for more domestic energy but often also to buy a variety of other things
- Some regression of LPG households to coal use took place where there were non-insulated structures on the same site as the participating household. Motivating factors may include the need for more extreme heat by some households or other factors
- There are very few indications that residents take ownership of the improvements, except in the group interviews, where a strong sense of ownership manifested
- People commented on how beautiful the ceilings make their houses. It has gone a long way to increase the sense of the house as "a place to feel at home", which is a deep need in these communities
- Trust in ESKOM and Nova is at a high level

1.3.1. Results from group sessions to obtain improvement/optimisation inputs

It is clear that maintenance will be needed of the improvements made to the houses: after one year there are already a number of complaints:

- Problems with ceilings: complaints are mostly about a few basic things (brown stains, opens up on the sides, cracks)

- Problems with KK: there is a variety of small problems, the most fundamental is uncertainty about how durable it will be. From group interaction, it was suggested that the Kitchen King could benefit from:
    - An oven rack
    - A more durable diagonal grid (on which the fire is made)
    - A more durable or more heat-resistant seal for the geyser tap
    - Access to cleaning material and consumables
    - Some training regarding the clearing of ash and poking of the stove
    - Availability of heat resistant black paint
    - LPG could be made more accessible – a local distribution point that accepts all cylinder brands would be welcomed

- Problems with LPG: there are fewer complaints than with the ceilings, also mostly about basic things (availability, cost, fear it is dangerous, the oven)

2. Activity 2: Second winter performance measurements of intervention variations

2.1. Methods

Activity 2 consisted of sub-activities aimed at monitoring energy use, fire cycles and indoor temperatures in a sub-selection of the retrofitted households.

2.1.1. Detailed Energy Survey

Interviews with an extended version of the DES questionnaire used for the household visits of 2014 and 2015 was conducted at 132 of the households between 28 July 2016 and 5 September 2016. It comprised a total of 17 sections and took 35 minutes on average to complete. The questionnaire captured data regarding the household's LPG use, electricity use, coal use, wood use, paraffin use, use of animal dung, sources of lighting, utility preferences, handling of garden rubbish and household waste (especially whether they burn it or not from time to time), cooking and heating utility preferences, status with regards to domestic safety issues, perceptions about their house, and expenditure on energy carriers.

To ensure that each interview was conducted with a competent and willing respondent, a series of qualifying questions preceded the interview. If the respondent qualified and provided consent, the interview proceeded; if not, the Nova fieldworker would return at a later stage to try again. In eight cases the Nova fieldworkers were never able to find a suitable respondent at home; the questionnaire was consequently only completed for 132 households, and not all of the 140 households targeted.

The questionnaire is available as a separate document: “Detailed Energy Survey ".

2.1.2. Coal weighing survey

During the second winter after implementation, Nova conducted another round of continuous coal weighing among the project households. A total of 47 households were included (19 of the 20 monitored Kitchen King intervention households; 18 of the 20 monitored electricity group households; and 10 control group households) and the measurements spanned a total of 84 days (from 4 August 2016 to 27 October 2016). The survey was conducted in the same way as in 2015: each fieldworker was assigned a number of households that they had to visit every three or four days. With each visit, the fieldworker had to measure the weight of the household's coal stock and also obtain information about any coal that the household had added to the stock since the fieldworker's last visit to the household (e.g. where did the household buy the coal, how much did it cost, how many units did they buy and how much did each unit weigh). The fieldworker also had to measure the amount of coal that the household typically used to start and refuel a fire. We then used this information to estimate the amount of coal used by each household per day.

2.1.3. LPG weighing survey

Nova also conducted an LPG weighing survey during the 84 days between 4 August 2016 and 27 October 2016. The LPG weighing was done in the exact same way as with the coal weighing described above; for this survey the fieldworkers simply had to measure LPG (in cylinder format) instead of coal. The survey was conducted in 29 households in total (nine basic retrofit households, eight 'basic-plus' retrofit households and 11 full retrofit households). All measurements were made using digital, hand-held scales.

2.1.4. Indoor temperature measurements

Nova placed DS1921G and DS1922L iButton® devices from Maxim Integrated™ in 77 of the project households to measure indoor dry-bulb temperature in the coldest room of each house (typically a south-facing bedroom) and to estimate the frequency and duration of the fires made by the household. The devices can measure temperatures between -40°C degrees and +85°C at a resolution of 0.5 °C. Three to four iButtons were placed per household: one iButton was placed in the coldest room of the house; a second iButton was placed at the coal or LPG stove; a third iButton was placed on the wall opposite the coal or LPG stove; and a fourth iButton was placed on the heater if the household had one.

The iButtons continually took measurements of the temperature every 10 minutes between 19 July and 11 December 2016. Three fieldworkers collected this data every two weeks using Nova's 1-Click iButton Reader application hosted on their Android devices. Some data loss did occur due to a flaw in the software but the final dataset nevertheless contains more than 1.1 million observations.

The 77 houses were made up as follows:

- 10 Kitchen King basic retrofit households
- 10 Kitchen King full retrofit households
- 10 basic retrofit households from the original electricity subsidy group (which received an electricity subsidy in winter 2015, but not in 2016)
- 9 full retrofit households also from the original electricity subsidy group (which received an electricity subsidy in winter 2015, but not in 2016)
- 10 basic retrofit LPG households
- 8 LPG basic-plus retrofit households
- 10 full retrofit LPG households

2.1.5. Prepaid electricity use

Nova undertook an analysis of pre-paid electricity data for KwaZamokuhle in order to determine if there was any significant change in electricity use due to the interventions from especially the LPG test group for the respective seasons.

We obtained data on pre-paid electricity sales from Steve Tshwete Municipality for KwaZamokuhle for 12 months, as well as from Eskom, as Eskom provides pre-paid electricity to KwaZamokuhle Extension 2. Considerable communication was required to interpret and analyse the data.

The dataset had to be extensively cleaned and formatted to address duplicate transactions, negative transactions and different household classifications. A series of checks and balances were implemented during the analysis phase to ensure data integrity.

There are two types of electricity users in the test group. The first group consist of households who are registered as indigent and therefore qualify for free basic electricity of 50 kWh per month. The owners or inhabitants of these houses are mainly unemployed. These households are fitted with a 20 amp main breaker to limit electricity use. The second category of users is domestic residential consumers (referred to as “lifeline users”) who only pay for the energy they use. These houses are fitted with a main breaker of 40 A per phase. It should be noted that 40 amp breakers (being smaller than the normal 60 or 80 amp breakers) entitles users to receive electricity at lower cost, but no 50kWh free electricity allowance.

Since the privacy of households is very important, we anonymised the data so as to ensure that a particular household cannot be identified.

The main aim of the analysis was to obtain reliable control group pre-paid values per month and per season. This was then compared with the test house data.

The two control groups were kept separate as the averages within the groups differ considerably. The main analysis was done with purchased and free units rather than expenses as the tariffs change every July. Winter months were defined as May, June, July and August while the remaining eight months were used for summer values.

2.1.6. Energy Inspection Survey

An Energy Inspection Survey (EIS) was conducted by Nova between the 22nd of August 2016 and the 10th of November 2016 at 116 of the 120 intervention households. The purpose of the survey was to:

- assess the quality and efficiency of the Kitchen Kings and LPG stoves after roughly one year of use
- assess whether users of Kitchen King stoves still used the stoves in a manner expected to result in low emissions
- obtain information about any LP gas-related accidents that might have occurred during the year
- determine if any LPG households lapsed into coal use with coal stoves
- assess the status of the installed ceilings, draft proofing after one year
- to assess each household's perception of their ceiling

Basic retrofit houses were inspected for problems such as gaps in the ceilings, loose cornices and damage or leakage. Full retrofit houses were additionally also inspected for damage to the insulation, plaster or paint on the north-facing wall outside. The locations of all solid fuel and LPG stoves were recorded for each household. All households were also asked to indicate how often they still used each of their stoves. LPG stoves and LPG heaters were inspected for damage to the knobs, clamps, regulators, pipes, cylinders and all other parts. Coal stoves were inspected for any sort of damage to the chimney pipe, body, door, water seal, the barrier between the chambers and damage to the ceiling surrounding the chimney. Where no damage could be found, that was reported as well.

2.1.7. Fire cycle monitoring

Fire cycle data for 2016 were collected through three avenues: (a) fire log sheets kept by the households on which they had to record every fire they made, along with the time and purpose of each fire; (b) questions in the Detailed Energy Survey on usual ignition times during winter and summer; and (c) iButton data for verifying and contextualising (a) and (b).

The fire logs were distributed on the 1st of August 2016 to all project households using coal. The Nova fieldworkers responsible for collecting iButton data were instructed to also check the households' fire logs on a regular basis to ensure that fire making events were recorded diligently. The logs were collected again from the households during the first week of January 2017. A total of 23 logs were returned. Upon inspection it became clear that many households neglected to record fire making episodes during December; consequently only the data from August to November 2016 were used for statistical analysis.

Dates and details concerning the DES 2016 and the iButton measurements are recorded in sections 2.1.1. and 2.1.4. above.

2.2. Results

2.2.1. Detailed Energy Survey

2.2.1.1. Coal use

Table 3: Summary of self-reported winter monthly coal use (kg) as captured in the Detailed Energy Surveys between 2014 and 2016

	Pre Intervention				Post Intervention				Post Post Intervention			
Intervention Type	**Mean**	**95% CI**	**n**	**Std Dev**	**Mean**	**95% CI**	**n**	**Std Dev**	**Mean**	**95% CI**	**n**	**Std Dev**
coal_basic	157,5	(124.08, 190.92)	15	60,35	146,2	(126.28, 166.07)	17	38,7	179,1	(152.79, 205.49)	20	56,3
coal_full	167,1	(133.2, 201.1)	19	70,44	139,9	(99.85, 179.97)	20	85,6	209,7	(169.14, 250.3)	19	84,19
control_none	143,7	(99.54, 187.9)	35	128,61	174,5	(134.86, 214.11)	17	77,07	120,9	(68.87, 172.91)	16	97,63
elec_basic	229,3	(177.75, 280.89)	17	100,31	170,9	(133.96, 207.77)	20	78,85	115,1	(74.45, 155.77)	20	86,87
elec_full	243,4	(209.72, 277.04)	14	58,3	126,7	(92.99, 160.33)	19	69,85	136,5	(85.72, 187.34)	19	105,41
lpg_basic	142,6	(97.06, 188.09)	16	85,41	20,63	(0, 52.93)	19	67,01	14,41	(0, 44.94)	17	59,4
lpg_full	239,6	(169.43, 309.8)	16	131,71	13,04	(0, 32.03)	20	40,57	7,16	(0, 22.2)	19	31,21

The results on winter coal use from three rounds of detailed energy surveys for the period before the interventions (column group 1, Pre Intervention), directly after the intervention (column group 2, Post Intervention) and one year after the intervention (column group 3, Post Post Intervention) is shown in Table 3. In each column group the mean, 95% confidence interval, number of observations and standard deviation of the winter monthly coal use (in kg) is given. The rows represent the different intervention groups. Table 4 below shows the same for summer.

Table 4 Summary of self-reported summer monthly coal use (kg) as captured in the Detailed Energy Surveys between 2014 and 2016

	Pre Intervention				Post Intervention				Post Post Intervention			
Intervention Type	**Mean**	**95% CI**	**n**	**Std Dev**	**Mean**	**95% CI**	**n**	**Std Dev**	**Mean**	**95% CI**	**n**	**Std Dev**
coal_basic	66,58	(33.92, 99.25)	15	58,99	62,07	(39.4, 84.74)	17	44,1	142,2	(115.87, 168.45)	20	56,18
coal_full	74,49	(48.38, 100.59)	19	54,15	60,89	(32.39, 89.4)	20	60,91	140,7	(107.53, 173.83)	19	68,79
control_none	51,87	(27.49, 76.25)	35	70,97	86,47	(51.43, 121.5)	17	68,14	90,28	(50.17, 130.39)	16	75,27
elec_basic	61,47	(28.1, 94.84)	17	64,9	76,32	(46.61, 106.03)	20	63,48	78,34	(43.01, 113.68)	20	75,5
elec_full	117,5	(51.76, 183.29)	14	113,9	48,5	(25.82, 71.18)	19	47,05	96,55	(57.71, 135.4)	19	80,59
lpg_basic	44,89	(13.35, 76.42)	16	59,18	1,02	(0, 3.16)	19	4,44	12	(0, 37.45)	17	49,5
lpg_full	90,81	(43.41, 138.21)	16	88,95	7,87	(0, 19.29)	20	24,4	5,37	(0, 16.65)	19	23,41

The coal consumption for the control group showed large variation but did not change significantly between the three periods. For the groups where the intervention involved the Kitchen King stove (coal_basic, coal_full), coal use also did not change significantly.

The groups where an electricity subsidy was provided in the first year but discontinued in the second year (elec_basic, elec_full) did not differ significantly from each other in each period but there was a significant decrease within the elec_full group from the Pre Intervention period to the Post Intervention and the Post Post Intervention period. The coal consumption of the elec_basic group was also significantly lower in the Post Post measurement compared to the Pre and the Post measurement. It should be noted that no electricity subsidy was provided in the Post Post Intervention period so the change in coal use cannot be construed as resulting from the electricity subsidy but more likely from the retrofit. It should also be noted that the elec_full, elec_basic and lpg_full groups had significantly higher initial (i.e. pre-intervention) coal consumption than the other intervention groups.

As expected, a drastic reduction in coal use is observed for the two groups where households' LPG stoves and heaters were exchanged for coal stoves. The coal use after the intervention was not zero however, because some households continued to use coal in a lean-to shack (that shares one wall with the main house) or freestanding shack. Expressed as a group average, the consumption in the periods after the intervention is very low because the mode value is zero.

Assuming that the South African climate has four winter months and eight summer months, the total amount of coal used per annum (in kg) by one household from each intervention type is calculated in Table 5 below.

Table 5: Coal consumption per annum per intervention type (in kg)

Intervention Type	Kg/m in winter	Kg/m in summer	Kg/a
coal_basic	179,1	142,2	1854
coal_full	209,7	140,7	1964,4
control_none	120,9	90,28	1205,84
elec_basic	115,1	78,34	1087,12
elec_full	136,5	96,55	1318,4
lpg_basic	14,41	12	153,64
lpg_full	7,16	5,37	71,6

2.2.1.2. LPG use

Table 6 below summarises the self-reported amount of LPG used (in kg) per month per LPG intervention household during the winter for each of the three periods.

Table 6: Self-reported winter monthly LPG use (in kg) among LPG intervention households. Source: DES 2014 - 2016.

	Pre Intervention				Post Intervention				Post Post Intervention			
Intervention Type	Mean	95% CI	n	Std. Dev	Mean	95% CI	n	Std. Dev	Mean	95% CI	n	Std. Dev
lpg_basic	0	(0.00, 0.00)	16	0	10,52	(6.92, 14.12)	19	7,47	11,9	(8.88, 14.93)	17	5,88
lpg_full	0	(0.00, 0.00)	16	0	11,6	(7.32, 15.88)	20	9,15	13,28	(7.75, 18.80)	19	11,47

No significant changes in reported LPG occurred between the period directly after the intervention ("Post Intervention") and a year after the intervention ("Post Post Intervention"): an lpg-basic household used an average of 10.52 kg LPG per month during the 2015 winter and a slightly higher 11.9 kg LPG per month during the winter of 2016; an lpg-full household used and average of 11.6 kg per winter month in 2015 and 13.28 kg LPG per winter month one year later.

The variance in both groups in both periods after the intervention is quite high.

2.2.1.3. Electricity use

The households' self-reported winter monthly electricity expenditure (R) is summarised below in Table 7:

Table 7: Self-reported winter monthly electricity use (in R) among all project households. Source: DES 2014 – 2016

	Pre Intervention				Post Intervention				Post Post Intervention			
Intervention Type	Mean	95% CI	n	Std. Dev	Mean	95% CI	n	Std. Dev	Mean	95% CI	n	Std. Dev
coal_basic	213,82	(93.40, 334.25)	14	217,46	202,38	(117.98, 286.77)	17	164,14	317,69	(252.40, 382.97)	9	139,49
coal_full	275,25	(189.21, 361.28)	17	178,5	204,45	(144.63, 264.27)	19	127,81	195,7	(134.19, 257.22)	14	127,63
control_none	222,64	(152.60, 292.69)	9	203,9	222,26	(154.49, 290.04)	17	131,82	207,76	(165.84, 249.67)	8	78,65
elec_basic	252,02	(186.63, 317.42)	16	127,19	231,02	(160.28, 301.76)	20	151,15	373,3	(164.39, 582.22)	13	446,39
elec_full	308,56	(207.06, 410.07)	14	175,8	228,11	(142.35, 313.87)	19	177,92	359,38	(180.47, 538.28)	12	371,19
lpg_basic	291,99	(187.71, 396.28)	14	195,71	365,93	(148.72, 583.13)	19	450,65	328,8	(175.64, 481.95)	13	297,88
lpg_full	307,64	(209.15, 406.13)	13	184,83	441,49	(231.67, 651.32)	19	448,33	266,32	(178.12, 354.53)	12	183

There are no statistically significant differences in reported electricity use between intervention groups in a given period, or within a given intervention group across the different periods. The only exception occurs in the Post Post Intervention period where the average electricity expenditure per winter month among the coal-basic households (R 317.69) is statistically significantly higher than that of the control group (R 207.76). The cause of this is unclear but given the large number of comparisons, it is not unexpected to get one spurious difference.

2.2.2. Coal weighing survey

The results from the coal weighing survey of 2016 is summarised in Figure 5 and Table 8 below.

Table 8: Coal consumption (kg) of all intervention types during summer and winter as recorded in the CWS of 2016 (Aug-Oct)

Intervention type	Season	Average kg/day	Median kg/day	95% CI	n	Std. Dev	Average kg/month	Exp. R/month
coal_basic	summer	2,3	2,86	(0.52, 4.08)	9	2,32	70,01	102,91
coal_full	summer	3,4	3,4	(1.72, 5.07)	10	2,35	103,49	152,13
control_none	summer	4,19	4,99	(2.34, 6.04)	9	2,4	127,53	187,47
elec_basic	summer	4,09	5,18	(1.84, 6.33)	9	2,92	124,49	183
elec_full	summer	4,33	5,07	(1.29, 7.36)	7	3,29	131,79	193,73
coal_basic	winter	4,88	2,35	(0.11, 9.64)	9	6,2	148,54	218,35
coal_full	winter	3,56	3,57	(1.85, 5.27)	9	2,22	108,36	159,29
control_none	winter	6,57	5,21	(2.03, 11.11)	6	4,33	199,97	293,96
elec_basic	winter	3,28	3,67	(1.18, 5.38)	7	2,27	99,84	146,76
elec_full	winter	2,73	3,72	(0.38, 5.08)	7	2,54	83,09	122,14

The mean daily coal consumption during winter for all groups is 4.1 kg/day; the median is 3.6 kg/day. The difference between the mean and the median is due to a number of very high observations, as is visible in Figure 12 below:

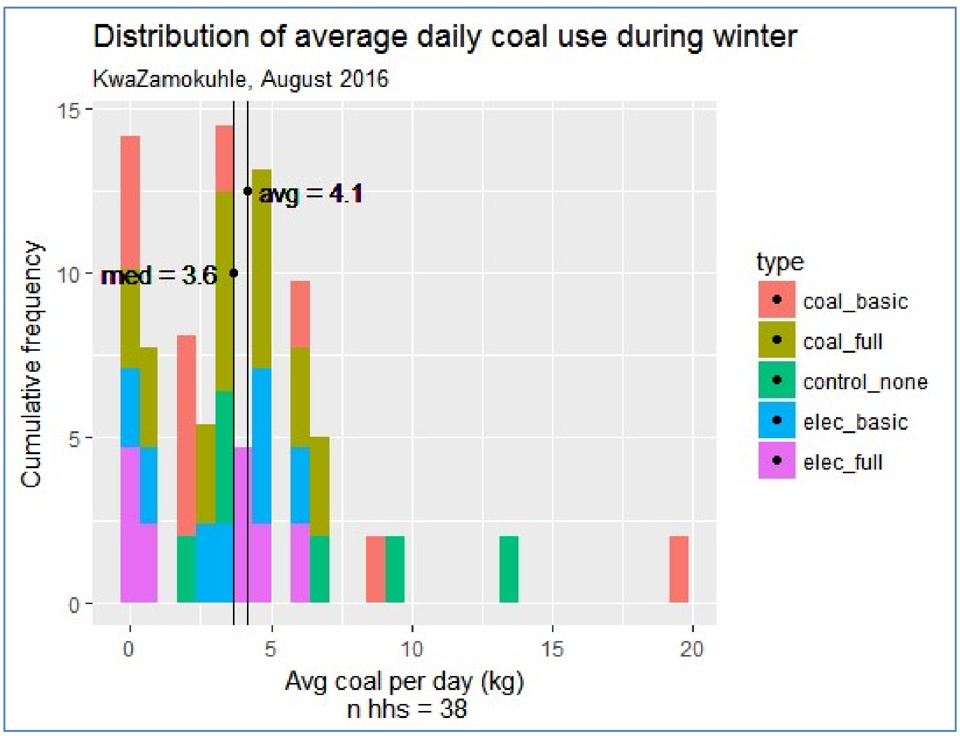

Figure 5 Distribution of average daily coal use (kg) during August (winter) as recorded in the CWS of 2016

One observation was more than three standard deviations higher than the mean. In this household (which belongs to the coal_basic group), a consumption of 80 kg was measured over 4.1 days, giving an average of 19.51 kg /day. The average use of another household was more than two standard deviations higher than the mean. In this household (which belongs to the control group), a consumption of 339 kg of coal was recorded over 25 days, resulting in an average of 13.56 kg/day.

From Table 8 above it appears as if the control households used more coal per day (6.57 kg) than any of the intervention groups (between 2.73 kg and 4.88 kg). This difference however does not appear to be statistically significant.

The monthly winter coal consumption from the coal weighing survey (128 kg/month or R 188 per month) compares well to the monthly consumption reported by households during the Detailed Energy Survey (152kg or R 224).

2.2.3. LPG weighing survey

Table 9 below summarises the winter LPG consumption (in kg) for LPG-basic and LPG-full households, as calculated from the LPG weighing survey data collected in 2016. Despite the seemingly large differences between the numbers for LPG-basic and LPG -full, the overlapping 95% confidence intervals show that these differences are not statistically significant.

Table 9: Winter LPG consumption per household as calculated from the LWS 2016

Intervention Type	Average kg/day	95% CI	n	Std. Dev	Average kg/month	Average R/month
lpg_basic	0,57	(0.17, 0.97)	13	0,66	17,35	380,83
lpg_full	1,08	(0.26, 1.90)	11	1,22	32,87	721,5

The high numbers for the LPG -full group are greatly influenced by the measurements for two households in particular - one for whom a total consumption of 56.1 kg was recorded over 14 days (i.e. 4 kg/day) and another for whom a total of 28.6 kg was recorded over 13 days (i.e. 2.2 kg/day). Figure 6 below shows clearly that these two measurements are outliers:

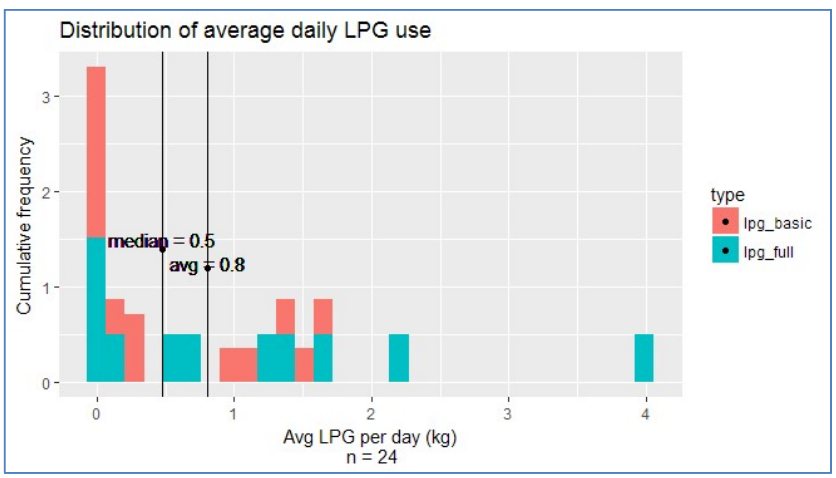

Figure 6: Average daily LPG use (kg) during winter as recorded in the LPG Weighing Survey of 2016

The LPG weighing survey measurements were marred by two specific fieldworker mistakes: (a) inconsistent deduction of cylinder weight from the measured weight and (b) use of wrong values for such cylinder weights; the results reflect the adjusted values. Due to the nature of the problems incurred as explained above, these results should be taken with caution and interpreted in conjunction with the DES results.

2.2.4. Results of indoor temperature measurements

2.2.4.1. Protection against minimum temperatures

The ability of the insulation interventions to protect against extremely cold temperature is an important performance criterion. Figure 7 shows instantaneous indoor and ambient temperatures for houses fitted with varying degrees of insulation, measured at the coldest indoor moment observed every morning (between 0:00am and 11:59am), averaged per insulation type; results are shown for the month of August.

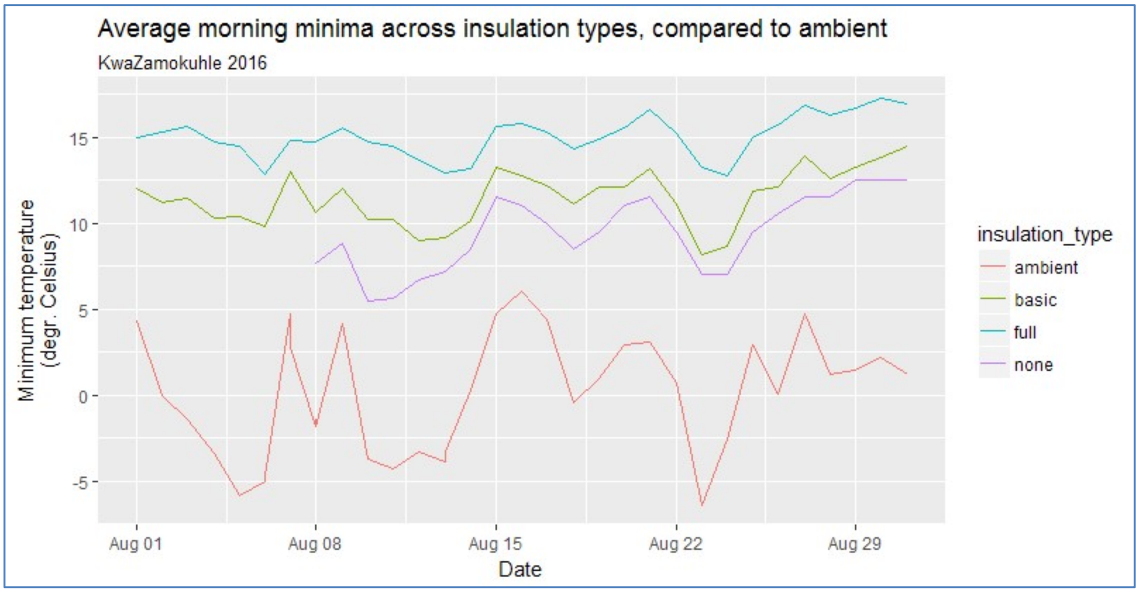

Figure 7: Average morning indoor minima across insulation types and compared to ambient (August 2016, winter)

There is a clear correlation between the ambient temperature and the indoor temperature. The uninsulated houses of the control group ("none") do offer some protection against the cold. The basic insulation brings about a visible improvement over the control group but the full retrofit outperforms both the uninsulated houses and the basic retrofit by far.

The basic-plus retrofit, tested between September and December 2016, fared better than the basic retrofit and seems to have brought indoor temperatures during the cool morning hours close to those of the full retrofit households (see Figure 8 below). Due to unfortunate data loss (as mentioned earlier), not much data is available for the full retrofit group during the basic-plus testing period.

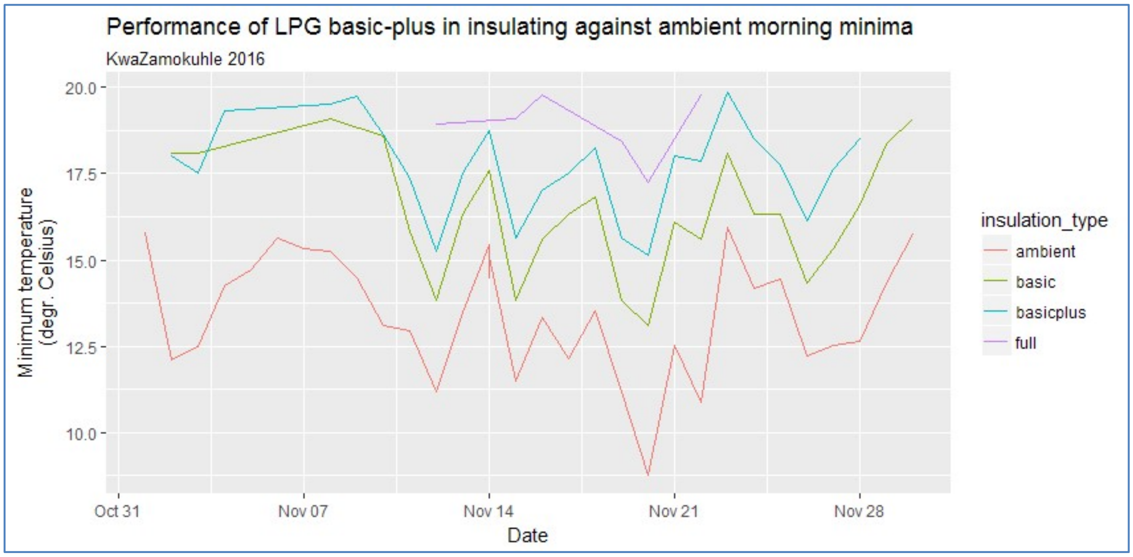

Figure 8: Performance of LPG basic-plus in insulating against ambient morning minima

2.2.4.2. Proportion of time in thermal comfort by season

Thermal comfort defined

Indoor thermal comfort *for waking hours* (defined as 6am to 10pm) = 18.9°C + 0.255*ambient temperature +/- 3.5K, lower limit 17.5°C, upper limit 29.5°C

Indoor thermal comfort *for sleeping hours* (defined as 10pm to 6am) = 18.9°C + 0.255*ambient temperature +/- 3.5K, lower limit 16.0°C, upper limit 29.5°C

Proportion of time in thermal comfort

The average proportion of time in thermal comfort is calculated by counting number of qualifying observations falling within the indoor thermal comfort temperature range, divided by the total number of qualifying observations.

The percentage of observed time for which the indoor temperature of the coldest room in the house was within the theoretical thermal comfort range for 80% of the population is given in the tables below (Table 10 - all seasons,

Table 11 - winter only, Table 12 - summer only):

Table 10 Percentage of time in thermal comfort range summarised by intervention type - all seasons

	coal_basic	coal_full	ctrl_none	elec_basic	elec_full	lpg_basic	lpg_bplus	lpg_full
comfortable	66,47	70,68	47,22	58,8	70,24	50,4	57,59	60,97
too.cold	24,28	25,16	40,9	31,8	25,23	47,29	42,41	37,28
too.hot	9,25	4,17	11,88	9,41	4,54	2,31	0	1,75

Table 11 Percentage of time in thermal comfort range summarised by intervention type - winter season

	coal_basic	coal_full	ctrl_none	elec_basic	elec_full	lpg_basic	lpg_full
comfortable	22,57	26,92	10,99	33,85	42,99	16,09	31,07
too.cold	76,66	73,07	89,01	66,15	56,41	83,91	68,42
too.hot	0,77	0,01	0	0	0,61	0	0,51

Table 12 Percentage of time in thermal comfort range summarised by intervention type - summer season

	coal_basic	coal_full	ctrl_none	elec_basic	elec_full	lpg_basic	lpg_bplus	lpg_full
comfortable	79,92	91,03	58,07	76,96	82,68	73,54	57,59	84,31
too.cold	8,23	2,87	26,49	6,78	10,99	22,58	42,41	12,98
too.hot	11,86	6,1	15,44	16,26	6,33	3,88	0	2,72

Looking at summer and winter combined, based on south wall measurements, the control group (a conventional RDP house where coal is used for heating) spent 41% of the observed time in temperatures that were too cold and 12% in temperatures that were too hot, leaving them slightly less than half of the time (47%) in thermal comfort.

The interventions where coal is still used, either in the Kitchen King or the old coal stove (coal basic, coal full, elec basic, elec full) experience a drastically smaller proportion of time exposed to cold (down to between 25% and 30%) compared to the control group. It is clear that the full retrofit protects against overheating since in the coal-using groups where a full retrofit was installed (coal full, elec full) it is too hot for only ~4% of the time (~6% in summer) compared to more than double that in the control group.

When comparing the LPG based interventions (LPG full, LPG basic, LPG basicplus), it is clear that these interventions performed worse than the coal intervention groups. Especially the LPG basic performs poorly in comparison to the control group and the interventions where coal is still used. When looking at the winter and summer months combined, it was too cold almost half the time (47.29%), compared to ~40% in the control group and 25%-30% in all the groups that had insulation and still used coal (Kitchen King or otherwise). During the winter months the LPG basic house was too cold for 84% of the time which, although poor, was still marginally better than the control group where it was too cold for 89% of the observed time.

The LPG basicplus houses performed better than the LPG basic houses but, although the time in thermal comfort (58%) was more than the control group (47%), the time spent in temperatures that were too cold was only marginally more (42% LPG basic+ vs. 41% Control); this is due to the fact that a large proportion of the thermal discomfort in the control houses was caused by overheating.

The LPG with full retrofit performed better than the control group in all metrics: more time in thermal comfort (61% vs 47%), slightly less time in temperatures that were too cold (37% vs, 41%) and significantly less time in temperatures that were too hot (2% vs 12%). The LPG basic plus as well as the LPG full was very successful in protecting against overheating, with only a very small proportion of time in summer spent in temperatures that were too hot (1% LPG basic+ and 3% LPG full compared to 15% for the control group).

Project activities

As a final analysis of thermal comfort experienced by the different intervention groups, generalised linear models (GLMs) were constructed for all groups to model their estimated indoor temperature. The models were constructed from the iButton measurements and corresponding ambient temperature data and were based on the following parameters:

a) Current ambient temperature
b) Ambient temperature 30 mins ago
c) Ambient temperature 60 mins ago
d) Ambient temperature 120 mins (2 hours) ago
e) Ambient temperature 6 hours ago
f) Ambient temperature 12 hours ago
g) Ambient temperature 24 hours ago
h) Ambient temperature 48 hours ago
i) Hour of day
j) Day of week
k) Day of month
l) Number of daylight hours for current day
m) Number of hours since from sunrise

Parameters (a) through (e) in conjunction with (i) allowed the models to be tuned for short-term changes in ambient temperatures, such as those due to onset of rain, overcast conditions or just the normal rising and setting of the sun. Parameters (d) and (e) also brought a structure's insulation capacity into play. Parameters (f) through (h), in conjunction with (l) and (m), allowed tuning for seasonal effects and other medium-term effects from phenomena such as cold fronts. The interplay between parameters (i), (j) and (k) aided in sensitising the models for changes in households' behaviour between, for example, weekdays and weekends as well as month-start and month-end.

Details about the models' attributes and goodness of fit can be found in Appendix 5.

The completed models were given the ambient temperature data from 2016, as measured by Eskom's monitoring station in KwaZamokuhle, from which it then had to predict the indoor temperature at a 10 minute interval for an average household from each of the different intervention groups.

The models' results were finally used to calculate the number of degree-hours outside thermal comfort for each of the intervention groups, where 1 degree-hour (°C.h) is equivalent to 1 hour at 1 degree Celsius away from thermal comfort (whether above or below). The results are displayed in Table 13 below:

Table 13 Degree-hours outside and within thermal comfort (tc) as estimated with the generalised linear models (GLMs) for all intervention types

Intervention Type	Total °C.h not in tc	°C.h under	Hrs under	Avg °C under	n days under	°C.h over	Hrs over	Avg °C over	n days over	Hrs in tc	n days in tc
control_none	16383	15516	4840	3,2	202	867	465	1,9	19	3411	142
lpg_basic	15048	14671	3826	3,8	159	376	330	1,1	14	4560	190
coal_basic	11777	11520	4228	2,7	176	257	241	1,1	10	4247	177
coal_full	11347	11298	3481	3,2	145	49	90	0,5	4	5146	214
elec_basic	9417	8963	3394	2,6	141	455	442	1	18	4881	203
elec_full	3989	3897	2504	1,6	104	92	90	1	4	6122	255
lpg_full	2912	2822	2407	1,2	100	91	94	1	4	6215	259

According to the models' estimations, the typical control household would have spent a total of 15516 degree-hours below thermal comfort in 2016. This, however, occurred during only 4840 hours, equivalent to 202 days constantly at 3.21 °C below the lower limit of the thermal comfort temperature range. The predicted difference in total degree-hours between the control group and the lpg_basic group is surprisingly small.

Next came the coal_basic households who would have spent 176 days constantly too cold at at least 2.72 °C below thermal comfort. This is 26 fewer days compared to the control group at roughly 0.5 °C warmer. In total, however, the coal_basic households would have spent 35 days more in thermal comfort than the control group, as the latter spent an additional 19 days overheating at at least 1.86 °C above the thermal comfort range's upper limit, while the coal_basic households would have spent only 10 days at 1.07 °C above thermal comfort.

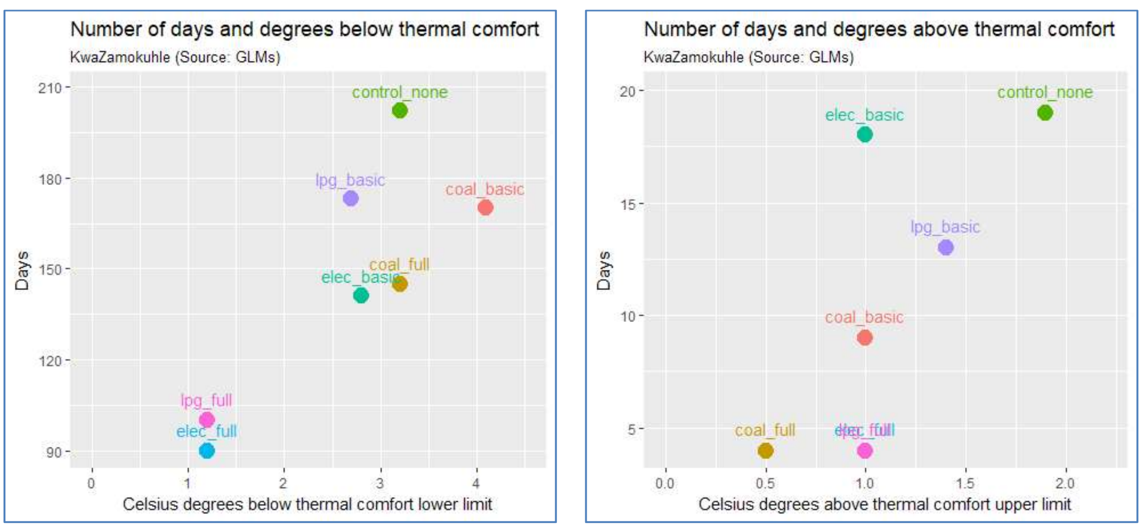

Figure 9 - Degree-hours below and above thermal comfort as estimated with the generalised linear models (GLMs) and translated to y days at x degrees from thermal comfort

The order of the coal_full and elec_basic is surprising and the general pattern is that full retrofit performs better than basic retrofit. The fact that both these groups continue to use coal may mean that the heat source in the elec_basic group plays a more important role than the insulation.

The elec_full and lpg_full households fared the best, spending only 104 and 100 days respectively below thermal comfort and each only four days above, resulting in a total of 255 days constantly within the thermal comfort range for elec_full and 259 days for lpg_full. Figure 9 above shows the degree-hours below (left) and above (right) the thermal comfort range translated to cumulative days and average degrees from thermal comfort. Although there is variation between individual households and the results presented above are modelled, the magnitude of the results and their relative order do give an indication of how a large group of each intervention can be expected to perform, on average, over the course of a typical year.

2.2.4.3. Diurnal pattern

The proportion of observed time where the indoor temperature of the coldest room in the house was within the theoretical thermal comfort range for 80% of the population is given in Figure 10 for every hour of the day and for two seasons.

Analysing the temporal distribution of thermal comfort episodes through the day emphasises the differences between the intervention types. Structures with less insulation fluctuate more. This is in the first place clear in the control group where the structure fails to provide protection against the falling ambient temperatures in the late afternoons and evenings and routinely cools down to thermally uncomfortable levels at night. At mid-day again the lack of insulation means that the control houses frequently overheat.

Houses with coal stoves and only basic insulation (coal_basic, elec_basic) were somewhat better off with a smaller proportion of the time below thermal comfort. The fact that the episodes of overheating that did take place occurred only later in the day shows that the mid-day heat gain was also slower than in the control group (as one would expect with a more insulated structure). Judging by the time of day and the fact that those episodes were absent in the LPG interventions, some of the overheating episodes later in the afternoon appear to be associated with internal heat sources such as the indoor use of a coal stove.

For the houses that were fitted with basic insulation plus draft-proofing and that used LPG we only have summer data available due to the implementation start date. These houses followed a distinctive pattern: the house warmed up slowly meaning that it was frequently too cold at mid-morning. Later in the day, however, the proportion of time that the structure was in thermal comfort increased. In the evening and early morning these houses did not perform as well as the full retrofit houses. The slight improvement above the basic only houses can be seen in the slackened heating during the mid-day period and as such the improved resistance against overheating in the mid and late afternoon on summer days.

The houses who received a full retrofit had fewer cold episodes overall because they maintained higher temperatures during the night. Practically no overheating took place in the middle of the day. However, where coal was used, a few episodes of overheating did occur in the afternoons. An interesting feature of the full retrofit houses is that periods of indoor temperatures below thermal comfort occurred more frequently in the middle of the day than in the evenings. This points to the slow heat gain of these structures. It also relates to the formula used in calculation of thermal comfort because thermal comfort is calculated as a function of ambient temperature (which rises rapidly through the course of the morning).

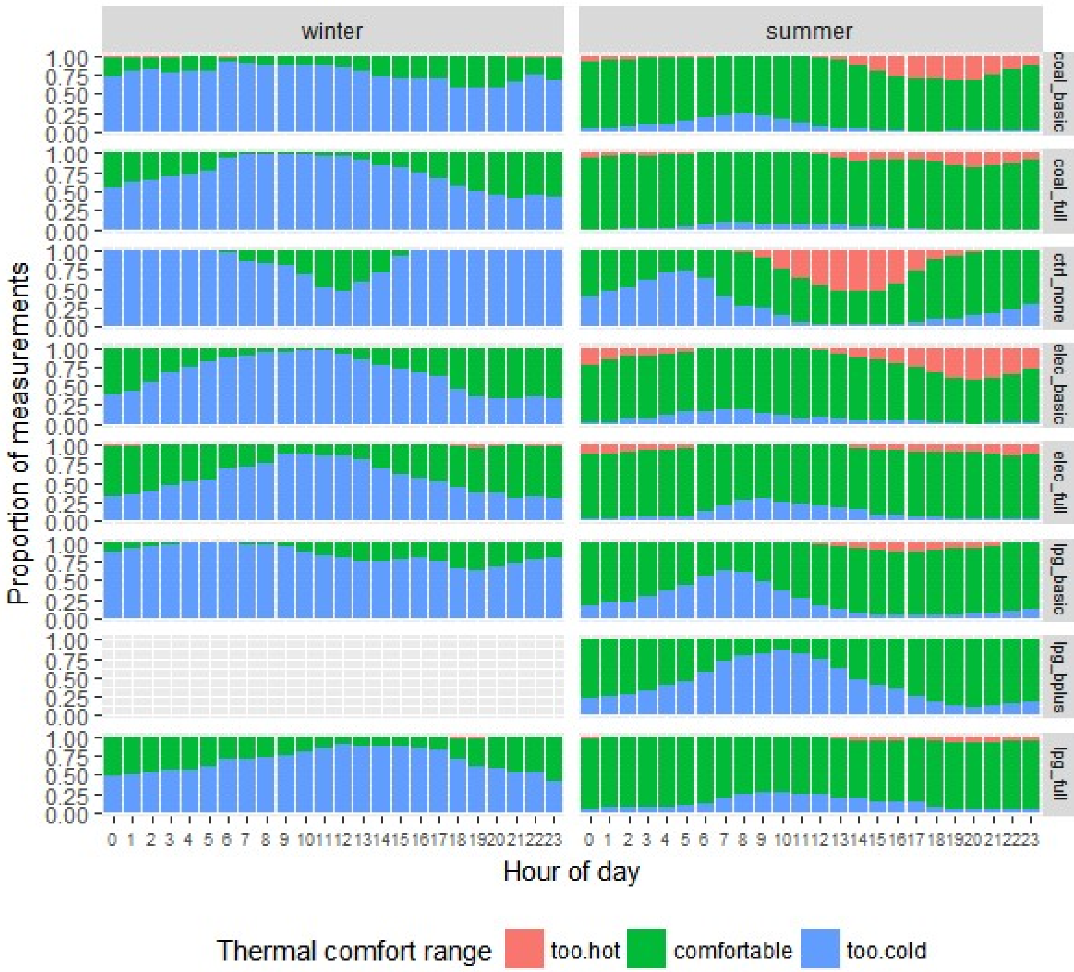

Figure 10 Proportion of time in thermal comfort per intervention type by hour of day and season

Compared to the control group the interventions brought about a change in the diurnal thermal pattern. In winter the pattern shifted from being too cold all the time, except sometimes during the middle of the day, to having cooler middays (sometimes uncomfortably so) but more thermal comfort in the evenings and early mornings (in the case of the full retrofit that is more successful in retaining heat). In summer the pattern changed from being comfortable for a fair proportion of the time with frequent overheating in the afternoon and being too cold for a fair proportion of the early mornings, to a situation where there is practically no overheating and the cold episodes occur slightly later in the day (when they do occur) for the LPG basic and LPG basic+ group. The LPG full intervention was particularly successful in summer with very little overheating and few cold episodes in the late morning. The intervention groups where coal was still in use performed the best of all in winter but did experience overheating on some summer evenings.

2.2.1. Pre-paid electricity use

The averages, standard deviations and 90% confidence intervals for pre-paid electricity use (in kWh units) and expenditure (R, incl. VAT) for the indigent group (municipal group of 2182 households) at

KwaZamokuhle who has a 20 A circuit breaker are shown in Table 14 for kWh units purchased and in Table 15 for Rand value.

The small difference between winter and summer usage indicates that electricity is probably not used for space heating due to limited budgets and the cost of electricity. There is also a municipal policy stating that the use of more than 600 kWh units per month for three consecutive months will result in cancelation of a household's registration as indigent. The indigent households who have four-plate electrical stoves with an oven report that they cannot use the oven simultaneously with the plates as the 20 A breakers cannot provide all the required electricity at once to do so.

Table 16 shows the consumption in kWh units for households (municipal group of 765 households) of the Lifeline group who has a 40 A circuit breaker. Table 17 shows the same in Rand. This group still qualifies for a special dispensation by not paying for electricity levies for the privilege of being connected to the network, but are prepared to forfeit the FBE to have more electrical power available at the same time. From the 91 test houses analysed, only seven houses belong to the Lifeline group. The consumption and expenditure for these seven households are shown in Table 18 and Table 19.

It is clear from these findings that the test houses did not spend more on electricity than the control[1] group.

1 *Due to availability of all the KwaZamokuhle pre-paid data, it was defined and used as the control group results*

Table 14: kWh units purchased by total KwaZamokuhle indigent code 501, 20 amp feeders, excluding Eskom feed (extension 2) plus 50 kWh free electricity

kWh units purchased by total Kwazamokuhle indigent code 501, 20 amp feeders, excluding Eskom feed (extension 2) plus 50 kw-hr free electricity														
Indigent Code 501 20 Amps		Date	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16
Season	Units (kWh)	Av kWh units	192	197	186	201	196	205	198	196	207	205	203	195
Winter	197	STDEV	136	130	121	128	121	128	127	120	125	124	126	130
Summer	199	90% CI	175-210	182-211	170-202	185-217	183-208	191-218	184-212	183-208	189-226	190-219	189-217	180-210
Count	2 182													

Table 15: Amount spent on pre-paid electricity for total KwaZamokuhle indigent code 501, 20 amp feeders, excluding Eskom feed (extension 2)

Amount pre-paid spend for total Kwazamokuhle indigent code 501, 20 amp feeders, excluding Eskom feed (extension 2)														
Indigent Code 501 20 Amps		Date	Jul-15	Aug-15	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Season	Amount incl.	Av amount incl.	R175	R179	R165	R184	R177	R186	R179	R174	R188	R185	R182	R175
Winter	R178	STDEV	155	147	135	144	136	142	144	134	143	140	143	148
Summer	R180	90% CI	R154-R196	R158-R199	R144-R185	R162-R207	R153-R200	R161-R210	R150-R208	R150-R199	R166-R210	R157-R213	R162-R203	R156-R193
Count	2,182													

Table 16: kWh units purchased by total KwaZamokuhle indigent group code 502, 40 Amp feeders, excluding Eskom feed (extension 2

Total Kwazamokuhle indigent code 502, 40 Amp feeders, excluding Eskom feed (extension 2)														
Lifeline code 502 40 Amps		Date	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16
Season	Units (kWh)	Av kWh units	298	306	279	290	276	286	274	266	288	286	296	300
Winter	300	STDEV	238	242	206	212	196	206	195	197	209	209	219	234
Summer	280	90% CI	281-316	287-325	262-296	272-308	261-290	269-303	258-289	251-281	272-305	269-303	277-314	281-319
Count	765													

Table 17: Amount purchased by total KwaZamokuhle indigent group code 502, 40 Amp feeders, excluding Eskom feed (extension 2)

Total Kwazamokuhle indigent code 502, 40 Amp feeders, excluding Eskom feed (extension 2)														
Lifeline code 502 40 Amps		Date	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16
Season	Amount incl.	v amount incl.	R423	R435	R392	R409	R386	R400	R383	R370	R406	R403	R419	R427
Winter	R426	STDEV	324	332	276	286	261	274	259	261	282	282	297	317
Summer	R394	90% CI	R380-R466	R386-R485	R352-R432	R383-R435	R355-R417	R376-R424	R352-R414	R348-R392	R363-R448	R372-R434	R394-R443	R379-R474
Count	765													

Table 18: kWh units purchased by KwaZamokuhle indigent test houses, excluding Eskom feed & excluding control houses

Kwazamokuhle indigent test houses, excluding Eskom feed & excluding control houses														
Test houses		**Date**	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Jan-16**	**Feb-16**	**Mar-16**	**Apr-16**	**May-16**	**Jun-16**
Season	**Units (kWh)**	**Av kWh units**	216	192	172	190	192	188	191	184	186	201	180	174
Winter	190	**STDEV**	122	98	92	100	90	91	89	92	81	100	81	90
Summer	188	**90% CI**	202-229	181-203	150-193	167-213	177-208	176-199	177-204	172-196	176-197	189-213	168-191	161-187
Count	83													

Table 19: Amount spent on prepaid electricity by KwaZamokuhle indigent test houses, excluding Eskom feed & excluding control houses

Kwazamokuhle indigent test houses, excluding Eskom feed & excluding control houses														
Test houses		**Date**	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Jan-16**	**Feb-16**	**Mar-16**	**Apr-16**	**May-16**	**Jun-16**
Season	**Amount incl.**	**v amount incl.**	R206	R177	R152	R176	R175	R171	R174	R166	R168	R185	R159	R154
Winter	R174	**STDEV**	165	122	109	120	116	110	109	114	99	127	99	110
Summer	R171	**90% CI**	R202-R211	R161-R193	R136-R167	R162-R190	R161-R190	R161-R181	R149-R200	R156-R177	R156-R181	R168-R202	R148-R170	R136-R172
Count	83													

The following histogram depicts the number of households within a specific kWh unit usage range. As expected it peaks within the range which contains the 190 kWh units per month (2000 to 2500 kWh/a) and shows clearly that the distribution is right skewed with a small number of household who consume large quantities of electricity.

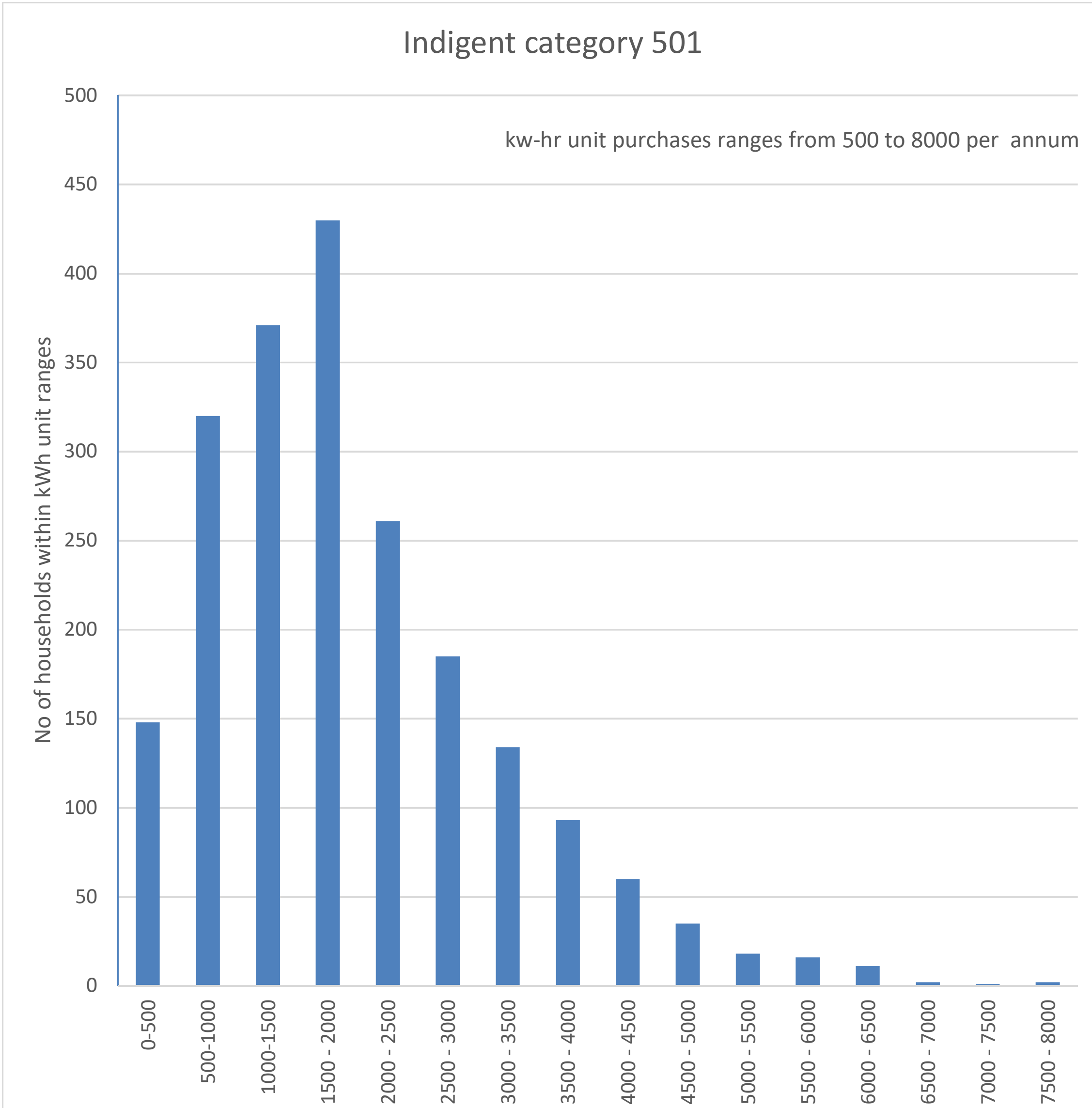

Figure 11 Histogram to indicate spread of average annual usage in kWh

Table 20 and Table 21 below give the kWh units purchased and the expenditure (incl. VAT) by the indigent test groups as well as the 90% confidence intervals.

There is not much difference in the winter/summer pre-paid kWh units between the combined test group averages and the large indigent control group. The 190/188 kWh average for winter/summer compares well with the 197/199 kWh of the indigent group. This leads to the preliminary conclusion that the interventions made little difference to electricity consumption.

A further analysis on the test group was to look at the post winter (2015) and post-post winter (2016) values for each of the intervention groups. Due to relative small numbers per group no significant conclusions can be made from the test group values.

The test 502 group used considerably less (282) kWh units in the 2016 winter than the large control group (409). This is interesting as the 502 group has more needs and funds for power. However, the test group with the same needs and funds used less kWh units which could possibly be explained by having less need for thermal energy.

Lastly an analysis was done per stand on its history of kWh units purchased. In the next table examples of six houses are shown:

Table 20: kWh units per month of the KwaZamokuhle test houses, excluding households fed by Eskom

kWh units per month of the Kwazamokuhle indigent test houses, excluding Eskom fed																
Average monthly pre-paid kw-hr units																
	Count		**Winter**	**Summer**	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Jan-16**	**Feb-16**	**Mar-16**	**Apr-16**	**May-16**	**Jun-16**
lpg basic T	**13**	**Av kWh units**	194	188	218	182	186	181	191	188	172	196	182	212	207	168
		STDEV			185	108	87	132	108	116	75	121	73	131	74	77
		90% CI			134-303	133-231	146-226	120-241	142-241	134-241	137-206	141-251	149-215	152-271	173-240	133-203
lpg full T	**18**	**Av kWh units**	209	199	221	216	212	213	197	207	212	163	188	203	196	201
		STDEV			124	116	90	95	66	108	105	80	78	80	78	89
		90% CI			173-269	172-261	177-247	176-250	171-223	165-249	171-253	132-194	158-218	172-234	166-226	167-236
coal basic T	**14**	**Av kWh units**	162	183	162	180	178	205	171	180	175	176	192	187	174	132
		STDEV			87	91	80	90	58	74	81	93	60	94	89	73
		90% CI			123-200	140-220	143-213	166-244	146-197	147-212	140-211	135-217	165-218	145-228	135-213	99-164
coal full T	**12**	**Av kWh units**	153	167	148	157	147	166	183	156	180	158	153	190	136	169
		STDEV			74	60	47	49	68	69	83	35	84	100	50	85
		90% CI			113-183	129-185	125-169	143-190	151-215	123-188	140-219	141-175	113-193	143-238	112-160	129-209
elev basic T	**15**	**Av kWh units**	203	186	275	200	124	179	193	196	205	203	199	187	171	165
		STDEV			111	108	122	124	133	103	108	120	102	113	106	101
		90% CI			228-322	154-246	72-175	126-231	136-249	152-239	160-251	152-254	156-243	139-234	125-216	122-208
elev full T	**11**	**Av kWh units**	217	201	267	206	173	186	223	190	190	213	202	233	191	205
		STDEV			71	86	86	91	93	56	71	73	89	87	65	109
		90% CI			232-302	163-249	130-216	141-231	177-269	163-218	155-226	177-249	157-246	190-276	159-223	151-259
Weighted Averages	**Total 83**		**190**	**188**												

Table 21: Amount pre-paid spend per month of the KwaZamokuhle test houses, excluding households fed by Eskom

Kwazamokuhle indigent test houses, excluding Eskom fed																
Average monthly pre-paid amount plus VAT																
	Count		**Winter**	**Summer**	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**	**Jan-16**	**Feb-16**	**Mar-16**	**Apr-16**	**May-16**	**Jun-16**
lpg basic T	**13**	**Av amount incl.**	R200	R199	R219	R182	R163	R190	R220	R224	R209	R196	R195	R193	R206	R192
		STDEV			200	96	113	123	175	149	160	155	120	151	131	146
		90% CI			R127-R310	R138-R225	R111-R214	R134-R246	R140-R299	R156-R292	R136-R282	R125-R266	R140-R250	R124-R262	R147-R266	R125-R258
lpg full T	**18**	**Av amount incl.**	R169	R148	R220	R191	R136	R148	R145	R152	R164	R140	R147	R153	R136	R128
		STDEV			165	145	149	139	89	88	119	91	91	125	98	109
		90% CI			R156-R284	R135-R247	R78-R194	R94-R201	R110-R179	R118-R186	R117-R210	R104-R175	R111-R182	R104-R201	R98-R174	R86-R171
coal basic T	**14**	**Av amount incl.**	R125	R151	R127	R132	R130	R163	R132	R147	R149	R170	R141	R174	R138	R103
		STDEV			89	94	86	89	63	47	67	82	76	78	63	65
		90% CI			R89-R166	R90-R173	R92-R168	R124-R203	R104-R160	R127-R168	R119-R178	R134-R206	R107-R174	R140-R208	R110-R165	R75-R132
coal full T	**12**	**Av amount incl.**	R205	R195	R221	R210	R190	R225	R213	R180	R176	R173	R190	R213	R187	R202
		STDEV			105	135	70	105	115	102	80	109	98	128	89	120
		90% CI			R171-R271	R146-R274	R157-R224	R176-R275	R158-R267	R131-R229	R138-R214	R121-R225	R144-R237	R152-R274	R145-R229	R145-R259
elev basic T	**15**	**Av amount incl.**	R173	R169	R188	R192	R146	R167	R174	R180	R185	R148	R183	R168	R158	R153
		STDEV			116	117	114	122	89	127	100	89	113	85	98	96
		90% CI			R139-R237	R142-R242	R98-R195	R115-R219	R136-R211	R126-R234	R142-R227	R110-R185	R135-R231	R132-R204	R117-R200	R112-R194
elev full T	**11**	**Av amount incl.**	R164	R163	R256	R131	R134	R168	R167	R142	R152	R181	R147	R211	R121	R149
		STDEV			271	128	84	135	135	123	105	161	87	191	88	94
		90% CI			R122-R391	R67-R195	R92-R176	R101-R235	R100-R234	R81-R202	R100-R205	R101-R261	R104-R190	R116-R306	R78-R165	R102-R196
Weighted Averages	**Total 83**		**R172**	**R169**												

Table 22: Amount pre-paid during the offset intervention phases by the respective test house groups compared to the large control group

Code 501: Kwazamokuhle test houses, excluding Eskom feed				
Average monthly kWh units purchased				
	Count	**Post Winter**	**Post-post winter**	**Mid Summer**
lpg basic T	7	264	223	234
lpg basicplus T	6	125	146	129
lpg full T	18	219	199	205
coal basic T	14	171	153	188
coal full T	12	153	153	175
elec basic T	15	237	168	186
elec full T	11	236	198	204
Weighted Averages	**Total 83**	**204**	**177**	**191**
Large control grp	**2 182**	**195**	**199**	**198**

Code 502: Kwazamokuhle test houses, excluding Eskom feed				
Average monthly kWh units purchased				
	Count	**Post Winter**	**Post-post winter**	**Mid Summer**
lpg basic T	2	216	240	259
lpg basicplus T	0			
lpg full T	0			
coal basic T	1	587	638	476
coal full T	2	148	187	204
elec basic T	1	243	358	342
elec full T	1	104	121	84
Weighted Averages	Total 7	**237**	**282**	**261**
Large control grp	**765**	**302**	**298**	**283**

Table 23: Example of individual test house history on purchased kWh units

			Winter month units			Summer month units		
Stand	Type	Indigent	Jul14	Jun15	Jun16	Nov14	Nov15	Feb16
x	elec-full	501	279	144	411	150	430	253
y	elec-full	501	259	213	90	154	175	183
z	elec-full	502	95	103	159	88	84	138
a	lpg-full	501	318	106	219	240	201	167
b	lpg-full	501	0	177	168	204	151	143
c	lpg-full	501	286	204	177	132	227	246

No clear conclusions could be made from the history trends. This explains why interviews and surveys need to be conducted to get a comprehensive understanding on energy use.

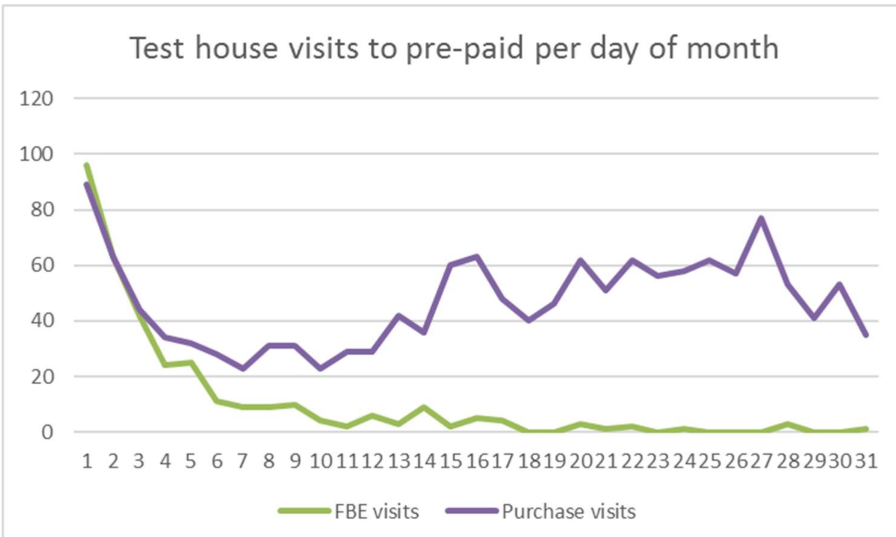

Figure 12 Test house visits to pre-paid office per day of the month

It is clear from these graphs that the households claim their FBE early in the month. As the FBE is depleted (50 kWh) after +/- 1 week they start to purchase more kWh units.

It was interesting to find a very small difference between winter (199 kWh/month) and summer (197 kWh/month) pre-paid kWh units obtained by more than 2000 registered indigent households in KwaZamokuhle. Further discussions are presented in Appendix 2: Detailed conclusions and recommendations from pre-paid electricity expenditure analysis.

2.2.2. Results from the energy inspection survey

The results of the energy inspection survey are given below. The inspection of ceilings revealed a variety of problems with only 23% of inspected ceilings that had no problems at all. The problem reported most frequently was that the ceiling boards have moved and left open holes (36%) while water stains where the second most frequently observed problem (34% badly stained). Cornices coming loose from wall or ceiling were observed in 28% of cases.

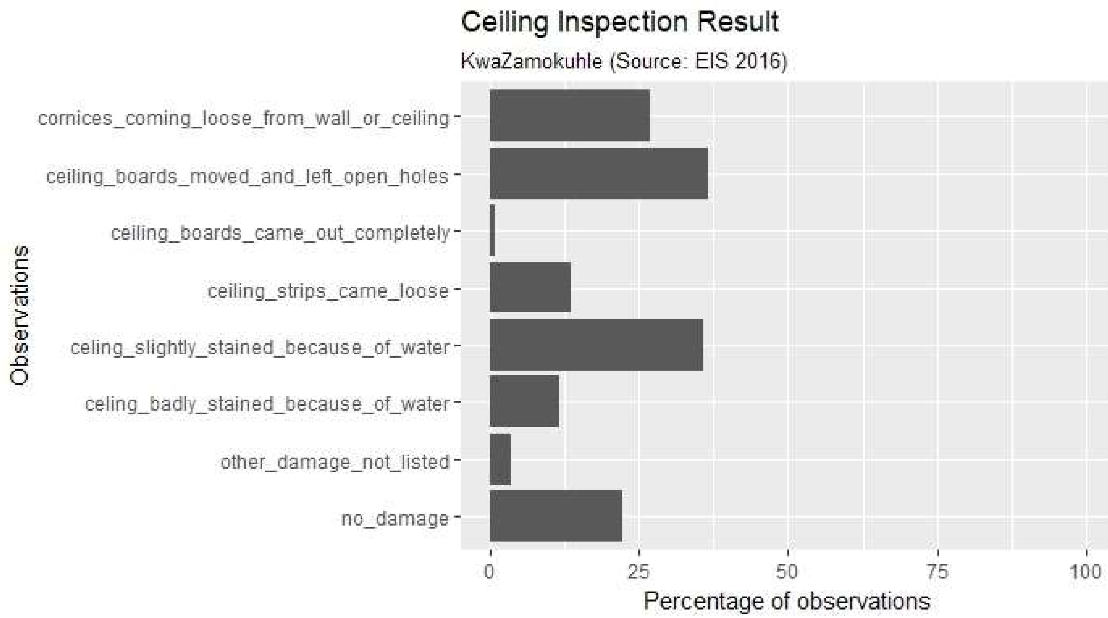

Figure 13: Problems experienced with ceilings

The wall insulation of the houses that received a full retrofit was also inspected. More than half (52%) of houses had no damage to the wall insulation. In 19% of cases the outside insulation or plaster was slightly damaged and in 19% of cases the dark paint of the north-facing wall was slightly damaged. Seven percent of the structures inspected had serious damage to the outside insulation or plaster.

Damages related to full retrofit	% Yes	% No
Problem with draft proofing	2	98
No damage	52	48
Damage to Trombe panel: slightly damaged	0	100
Damage to Trombe panel: badly damaged	0	100
Damage to outside insulation or plaster: slightly damaged	19	81
Damage to outside insulation or plaster: badly damaged	7	93
Damage to dark paint of north facing wall	19	81

The results of inspection of the Kitchen King stoves are shown in Table 24. Slightly more than a third (38%) of households experienced no problems with the Kitchen King. The most common problems experienced were damage to the water seal (32%) and cracks in the body of the stove (24%).

Table 24: Problems with the Kitchen King

Problems with the Kitchen King	% Yes	% No
Water seal damaged	32	68
Other specify	3	97
None of the above	38	62
Kitchen King door not closing properly	3	97
Indoor crack or leak on chimney pipe	0	100
Cracks in body of Kitchen King	24	76
Ceiling molten or burnt where chimney passes through ceiling	6	94
Body of Kitchen King burnt through or cracked	12	88
Barrier between coal burning chamber and smoke burning chamber damaged broken through	9	91

2.2.3. Results of fire cycle monitoring

Figure 14 below shows the results from the fire log sheets kept by the households. The control group recorded the most fires per day during winter with an average of 1.52 fires per day. The elec-basic group followed, virtually matching the control group with 1.51 fires per day on average. The coal-basic group came in third, recording an average of 1.16 fires per day. The full-retrofit households filed last with an average of 1.03 fires per day during winter for coal-full and 0.93 fires per day for elec-full. These numbers are aligned with what can be expected – the control group, having the least insulation against temperature extremes, made the most fires during winter; the basic retrofit households, having a bit more insulation than the control group, made fewer fires during the winter but not as few as the full retrofit groups which had the most insulation.

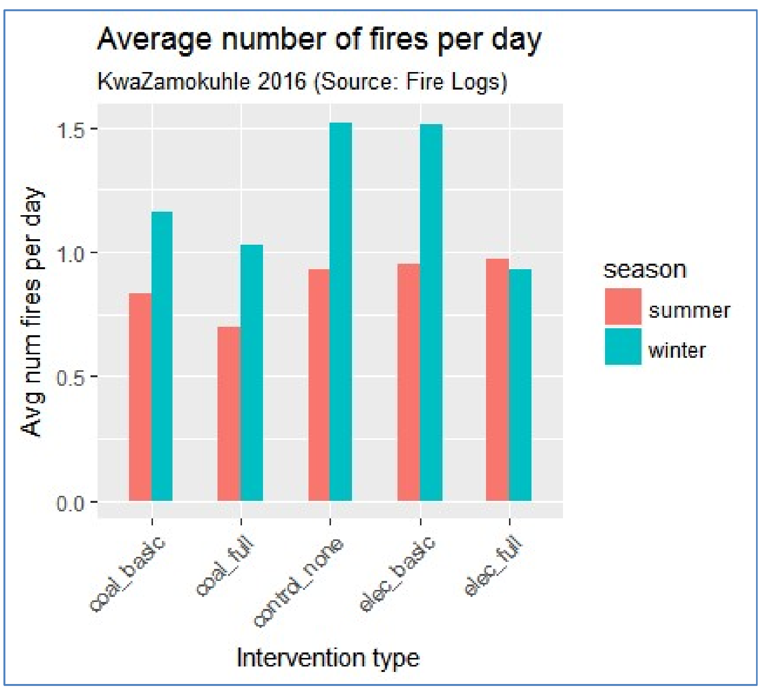

Figure 14 Average number of fires per day as recorded in the households' fire logs between August and November 2016

The responses to the ignition time questions in the DES of 2016 are summarised in Figure 15. The graph displays the proportion of fires made by hour of day and season for each of the intervention groups (LPG groups excluded). Vertical lines drawn at 11 am indicate the total proportion of daily fires made by that time. During winter all intervention groups make the greatest proportion of their fires before 11 o'clock in the morning, the majority thereof being made between the hours of 5 and 8 am.

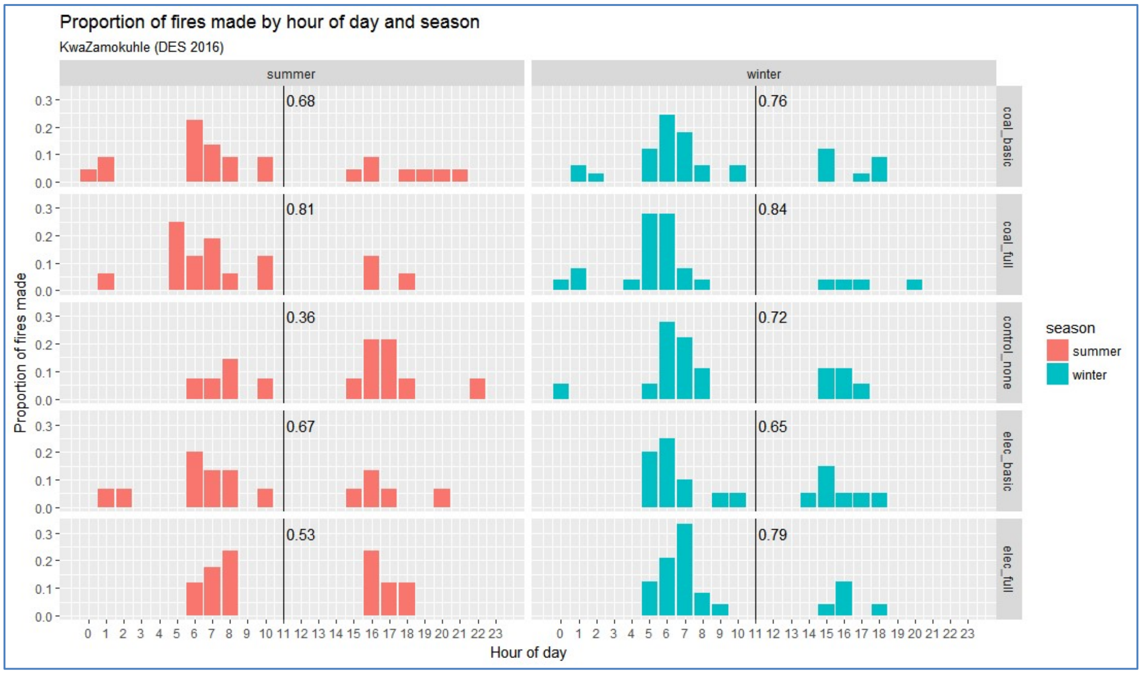

Figure 15 Proportion of fires made by hour of day and season as captured in the DES of 2016

This pattern changes for the summer months to different extents for the different intervention groups. By 11 am on a summer morning, the control households have only made 0.36 of their daily fires; the majority now being made between 15:00 and 18:00. The numbers for elec-full drop from 0.79 at 11 am in winter to 0.53 at 11 am in summer with virtually the same proportion of fires made between 05:00 and 08:00 as between 15:00 and 18:00. The proportions for the other groups only change with between -0.08 and 0.02 from winter to summer. The exact numbers are displayed in Table 25.

Table 25 Proportion of fires per hour of day and season (‘S’ = summer, ‘W’ = winter) as captured in the DES of 2016

	Coal-basic		Coal-full		Control		Elec-basic		Elec-full	
Hour of day	**S**	**W**	**S**	**W**	**S**	**W**	**S**	**W**	**S**	**W**
0	0,05	0	0	0,04	0	0,06	0	0	0	0
1	0,09	0,06	0,06	0,08	0	0	0,07	0	0	0
2	0	0,03	0	0	0	0	0,07	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0,04	0	0	0	0	0	0
5	0	0,12	0,25	0,28	0	0,06	0	0,2	0	0,12
6	0,23	0,24	0,12	0,28	0,07	0,28	0,2	0,25	0,12	0,21
7	0,14	0,18	0,19	0,08	0,07	0,22	0,13	0,1	0,18	0,33
8	0,09	0,06	0,06	0,04	0,14	0,11	0,13	0	0,24	0,08
9	0	0	0	0	0	0	0	0,05	0	0,04
10	0,09	0,06	0,12	0	0,07	0	0,07	0,05	0	0
11	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0,05	0	0
15	0,05	0,12	0	0,04	0,07	0,11	0,07	0,15	0	0,04
16	0,09	0	0,12	0,04	0,21	0,11	0,13	0,05	0,24	0,12
17	0	0,03	0	0,04	0,21	0,06	0,07	0,05	0,12	0
18	0,05	0,09	0,06	0	0,07	0	0	0,05	0,12	0,04
19	0,05	0	0	0	0	0	0	0	0	0
20	0,05	0	0	0,04	0	0	0,07	0	0	0
21	0,05	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0,07	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0

3. Activity 3: Assess potential intervention improvement

3.1. Methods

We conducted an investigation into alternatives to EPS insulation through an internet and literature survey and in consultation with industry experts and potential suppliers. We shortlisted alternatives and assessed their potential resistance to excessive moisture and other challenging in-house conditions. The most promising alternatives were selected and tested according to SANS requirements for use in domestic dwellings.

Secondly, draft proofing was installed in 10 LPG basic houses. Draft proofing consisted of window pane replacement where broken, insulation of steel doors and replacement of doors with excessive gaps. Indoor temperatures were measured using iButtons mounted on the south wall in the same 10 LPG basic houses as well as 10 LPG full houses. The iButtons were set with an average period of 10 minutes and had a resolution of 0.5 °C. The monitoring started on 7 September and continued until 11 December 2016.

In order to assess whether the older Kitchen King stoves are still effective after long-term use we consulted with the supplier of the Kitchen King in order to locate users of the stove who have been using the stoves for a number of years. We identified a suitable group of users on a farm near Standerton.

To assess how the KwaZamokuhle users of Kitchen King stoves operate/experience their stoves after a year in use, we drafted a structured questionnaire and tasked an experienced project coordinator to interview participants and examine their stoves. The coordinator conducted 34 interviews (85% of participating group).

We intended to assess household experience of an intervention that combines cooking with LPG and space heating by means of electric heater, in a retrofitted environment but this investigation did not take place due to the small number of heaters in the LPG homes and was factored into the initial lead implementation scope.

3.2. Results

3.2.1. Alternative insulation assessment

Nova with its network partners assessed possible alternative insulation systems applicable to the conditions encountered in typical coal-using households. The presence of excessive moisture coupled with unsecure substrates and poor construction practices disqualify conventional insulation systems. The use of EPS was an attempt to counter these conditions, but the Eskom KwaZamokuhle pilot study showed that some problems still remain.

The most promising alternatives assessed were the following:

3.2.1.1. Spray polyurethane foam

Spray polyurethane foam (SPF) is made by mixing reacting chemicals to create a rigid foam. The reacting materials react very quickly, expanding on contact to create foam that insulates and provides a moisture barrier and air seals. SPF insulation is known to resist heat transfer extremely well, and it offers a highly effective solution in reducing unwanted air infiltration through cracks, seams, and joints.[2] Polyurethane is widely used in North America and Europe to insulate homes in adverse weather zones. Applicability to local conditions has to be evaluated by going through Nova's different phases, including prefeasibility, feasibility and pilot activities.

The main advantages of SPF are:

- It has great insulation properties
- Its closed cell structures makes it waterproof
- It is a spray-on product which sticks easily to surfaces and expands into holes, cracks and openings
- It is cost effective
- It is easy to maintain

The main concerns regarding the use of SPF are:

- If not applied/mixed correctly it can produce irritants which cause sensitive people harm
- SPF have employed harmful blowing agents in the past, both to human health and the environment (one should ensure that only modern benign blowing agents are used)
- It is combustible and produces hydrogen cyanide when burning. Because of its combustibility it requires the use of flame retardants, and we need expert advice on the risks involved in this particular context
- Long-term maintenance by residents has to be determined
- Installation risk

Nova requested a quotation from Arctic Insulation, a company that offers Ecomate SPF. Ecomate is an environmental friendly, benign blowing agent and its systems has no global warming potential (GWP), no ozone depleting potential (ODP), and is free from volatile organic compounds. Ecomate fulfils current RSA regulatory requirements and is both U.S. EPA and SNAP approved[3].

3.2.1.2. Spray-on ceramic insulation

Ceramics can be defined as inorganic, non-metallic materials. They are typically crystalline in nature (having an ordered structure) and are compounds formed between metallic and non-metallic elements such as aluminium and oxygen (alumina), calcium and oxygen (calcia), and silicon and nitrogen (silicon nitride).[4]

Ceramic spray-on insulation (CSI) can be based on polymer chemistry that is amorphous rather than crystalline in nature. Crystalline liquids dry to a bed of thousands of tiny individual crystals, which can separate under maintenance traffic, temperature variations, or normal building flexion. Amorphous chemistries produce a random molecular structure, drying to a fibrous, continuous film, with significantly more elasticity than for example fiberglass felt.[5]

The main advantages of CSI are:

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[2] https://spraypolyurethane.org/Main-Menu-Category/Consumers/SPF-Insulation-Basics
[3] Ecomate product broshure: http://ecomatesystems.com/ecomate-resources/fsi-brochure.pdf
[4] http://ceramics.org/about/learn-about-acers/acers-faq
[5] http://www.supertherm.net/multicera.htm

- CSI is a single compound application which lower the application risk
- CSI is typically incombustible
- CSI is waterproof
- CSI can have exceptionally high reflection characteristics thereby insulating against all three spectrums of heat waves

The main disadvantages of CSI are:

- CSI employs mainly reflective functions in order to contain/deflect heat and it is highly questionable whether the insulation properties will measure up to standard materials
- Reflective capabilities deteriorate rapidly in the presence of dust or dirt, and over time
- There is no substantial body of data from residential insulation tests using CSI, thereby leaving a question mark over the applicability and efficacy of CSI in residential applications
- Moderate to high need for maintenance
- Cost

Nova approached Sharpshell Industrial Solutions who supplies both Supertherm (USA product) and Duocote (EU product). A site visit and technical presentation showed that Duocote is applied with relative ease and has less installation risks than for example SPF. Duocote is extensively used in industrial applications where heat insulation is needed. Application devices range from hand-held spray vessels to compressor-driver large volume units.

3.2.1.3. Cellulose insulation

Cellulose insulation is a plant fibre used in wall and roof cavities to insulate, draught-proof and reduce noise. Many types of cellulosic materials have been used, including newspaper, cardboard, cotton, straw, sawdust, hemp and corncob. Modern cellulose insulation made with recycled newspaper using grinding and dust removing machines and adding a fire retardant, began in the 1950s and came into general use in the US during the 1970s. Applications include dry- and wet sprayed-, stabilised- and low dust cellulose.

The main advantages of cellulose insulation are:

- The thermal insulation properties of cellulose compares favourably to popular products such a fiberglass wool
- The borates typically used as fire retardants in cellulose applications are benign and may enhance pest control
- Cost-effective

The main disadvantages of cellulose insulation are:

- It is not waterproof
- Spray-on applications have an unfavourable weight characteristic making it unsuitable for retrofitted underroof application
- Cellulose may contain fine particles/dust to which residents may be exposed
- If a vapour barrier is used to resist moisture there is evidence that mould forming can be elevated

3.2.2. Assessment conclusion

Nova's assessment concluded that a SPF based ceiling system has the best potential to address the challenges encountered in houses. It is the only waterproof insulation product identified with a proven record of good insulation properties and durability.

3.2.3. Hazard identification

Nova's hazard assessment has identified the following two major health and safety hazards associated with SPF use:

Project activities

Intervention	Identified hazard	Description	Possible impact	Likelihood	Proposed action
Insulation	Off-gassing and/or harmful emissions after installation.	SPF may produce VOC emissions after application which could negatively impact household members' health.	Significant. Irritation of air ways. Sensitisation to specific substances.	Low. Modern SPF applications use eco-friendly blowing agents which react fully in a short time after application. Blowing agents are controlled by South African legislation which prohibits the use of harmful agents. USA studies show that particulate emissions are most likely due to erroneous mixing of polyols. Mixing is today controlled by sensitive flow meters and cut-out switches ensuring seizure when mixing is inadequate.	Ensure high-quality, certified blowing agents are used. Apply SPF with sophisticated rig which will ensure accurate flow rates and mixing.
Insulation	Fire	SPF is an organic combustible material and might contribute to propagating fire.	Severe. If SPF propagates fire it might have serious consequences for human health during/following a fire.	Unknown. We need an expert opinion in terms of the most appropriate fire curves relevant to the installation we plan within this context	Assess SANS guidance/standards on fire risk assessment. Involve knowledgeable industry representatives to assess requirements and considerations. Test and verify all designs according to SANS specification before installation. Get expert advice regarding the extent of material testing that is needed.

3.2.4. SANS fire performance requirement and initial testing

Following the hazard identification process, Nova commissioned fire tests at the Fire Lab (CSIR, Pretoria) on the chosen SPF insulation.

SANS10400 – T: Fire Protection stipulates under 4.5.3 that "...any insulation, insulating panel or lining used as a thermal insulation system under an external covering as part of a roof or wall assembly (thermal insulated building envelope), tested in accordance with SANS 10177-5 and found to be combustible, shall be acceptable if, when classified in terms of the SANS 428 protocol, its use and application are acceptable."[6]

As SPF is organic and thus combustible, the relevant SANS 428 classification system is:

Surface fire properties			Classification
Small-scale application[a]	Large-scale application[b]	Behaviour of material	
Flame height from fire source mm			
≤ 2 000	≤ 4 000	No flame spread	B1
≤ 3 000	≤ 6 000	Low flame spread (no flaming droplets or burning brand)	B2
		Low flame spread (with flaming droplets or burning brand)	B3
≤ 4 000	≤ 8 000	Average flame spread (no flaming droplets or burning brand)	B4
		Average flame spread (with flaming droplets or burning brand)	B5
> 4 000	> 8 000	Rapid fire spread	B6

[a] When determined in accordance with SANS 10177-10.
[b] When determined in accordance with SANS 10177-11.

In order to apply insulation under roof in domestic residences, the insulation needs to achieve a B3 rating or better.

In accordance to the above Nova commissioned two tests, namely a small-scale vertical (SANS 10177-5) and a horizontal fire-spread test (SANS 10177-10). The tests were conducted on 12 and 19 July respectively. The test material failed the SANS 10177-10 test as the flame spread was more than 3000mm and thus exceeded the B3 rating allowance. This made the particular material tested unfit for use in a domestic environment.

[6] https://law.resource.org/pub/za/ibr/za.sans.10400.t.2011.html

3.2.5. Alternative insulation design

3.2.5.1. Planning

Following the initial fire tests and product evaluation described under 4.1.7. Nova invited proposals from its network partners on alternative insulation options. Nova sought to answer the following questions:

- Why does the SPF product we tested perform so much worse than what is used internationally and what we expected?
- Do we have safer SPF products available in SA?
- Can we mitigate the risk by preventive design, e.g. the installation of a fire barrier?
- If not, what other viable insulation options do we have?

The outcomes of this enquiry were:

- The foam Nova tested initially was probably of lower quality than foam used in residences internationally
- Better quality SPF than the tested specimen has been developed and used in South Africa, specifically as a fire barrier in mines
- Internationally produced SPF is available in South Africa and should be tested
- The test specimen configuration should be reflective of the entire ceiling system and wall cladding and not just SPF panels

3.2.5.2. Follow-up testing

3.2.5.2.1. Alternative SPF options

During September to October 2016 Nova received sample SPF products from three producers for testing. These products originated from the USA, Spain and China where SPF is widely used and according to documents provided passed the necessary safety tests in their respective environments.

3.2.5.2.2. Preliminary fire tests

During August 2016 Nova and Arctic Insulation constructed and configured a test rig according to SANS 10177-10 specifications:

Project activities

Figure 16: SANS 10177 test apparatus

Nova conducted seven SANS 10177-10 tests on ceiling system specimens. The specimens all represented different installation configurations and tested flame spread when employing various elements like intumescent paint, fire retardant non-intumescent paint and cement fibre ceiling boards. Several of the tests provided positive results, in as much as the flame spread was clearly less than three meters and thereby could achieve B3 rating. It seemed possible that some of the combinations could achieve a B1 rating meaning that there is no flame spread beyond the initial 2 meter ignition area:

Figure 17: SANS 10177-10 test run and ignition area post-run

Figure 18: SPF surface in ignition area (<2m)

Figure 19: Fire spread analysis

3.2.5.2.3. Final fire testing

On 21 November 2016 Nova conducted a SANS 10177-10 fire propagation test which was verified and validated by a fire engineer:

Project activities

The test report classified the installation as “B/B1/1/H/USP and the roof envelope is viewed suitable by the assessor to be used in Category 1 buildings and in H3 and H4 buildings based on the SANS 428 test and classification regime provided that the H3 and H4 buildings are not more than two stories in height.” Please see Appendix 4: Assessment of Fire Test and use classification of roof envelope section in accordance with SANS 428 for the full report.

The configuration of the final test sample requires a 25-30mm SPF layer applied to the underside of the roof, covered by a layer of intumescent paint and protected with a standard gypsum ceiling as barrier.

3.2.6. Draft proofing results

The performance of the LPG basic-plus intervention compared to the LPG basic, LPG full and control groups in terms of indoor morning minima is indicated in Figure 20 below. The figure shows instantaneous indoor and ambient temperatures for houses fitted with varying degrees of insulation, measured at the coldest indoor moment observed every morning (between 0:00am and 11:59am), averaged per insulation type.

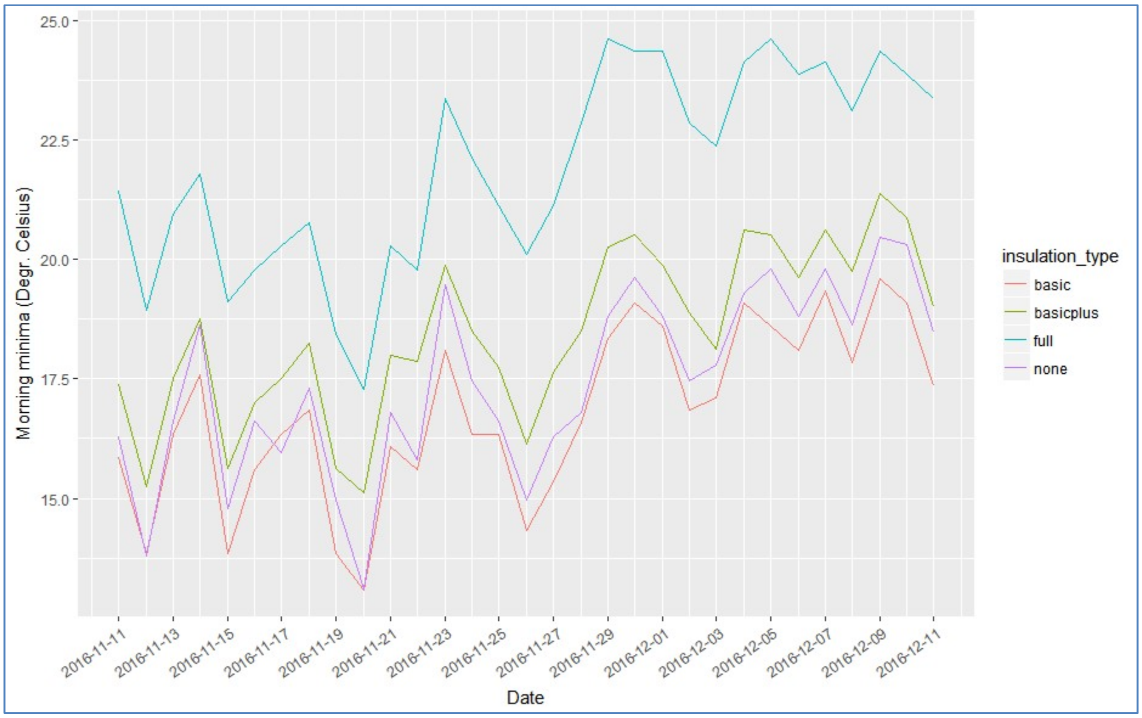

Figure 20 Performance of LPG basic-plus households in terms of instantaneous indoor morning minima, compared to LPG basic, LPG full and control households (Period: 11 Nov - 11 Dec 2016)

The basic-plus performed statistically significantly better than the basic retrofit households, the former being on average 1.66 Celsius degrees warmer than the latter. The full retrofit, however, still outperformed the basic-plus with an average indoor minimum temperature of 21.92 Celsius degree, which was statistically significantly higher than the 18.46 Celsius degree indoor morning minimum of the basic-plus. Table 26 summarises the results:

Table 26 Morning minimum temperatures (°C) across different insulation types for households using LPG as main energy carrier (Period: 11 Nov - 11 Dec 2016)

Intervention Type	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	n	ci_lower	ci_upper	Std. Dev
lpg_basic	13,09	15,72	16,84	16,8	18,22	19,6	31	16,14	17,47	1,81
lpg_basicplus	15,12	17,5	18,5	18,46	19,88	21,38	31	17,81	19,1	1,76
lpg_full	17,27	20,27	22,11	21,92	23,86	24,61	31	21,15	22,68	2,08
control_none	13,12	16,29	17,46	17,43	18,8	20,47	31	16,72	18,14	1,93

The thermal comfort performance of the LPG basic-plus intervention over the course of a day is compared in Figure 21 with that of the LPG basic, LPG full and control groups. The basic-plus intervention retains heat longer than the basic intervention, resulting in more comfortable indoor temperatures in the deep of the night. The basic-plus, however, also takes longer than both the basic and control households to gain heat, resulting in a smaller proportion of thermal comfort during the hours between 7 am and 11 am. Where the control and basic households often overheat on summer afternoons, the basic-plus virtually never overheats. As can be seen, the full retrofit intervention almost constantly out-performed all three other intervention groups. For exact figures, please refer to Section 2.2.5.2.

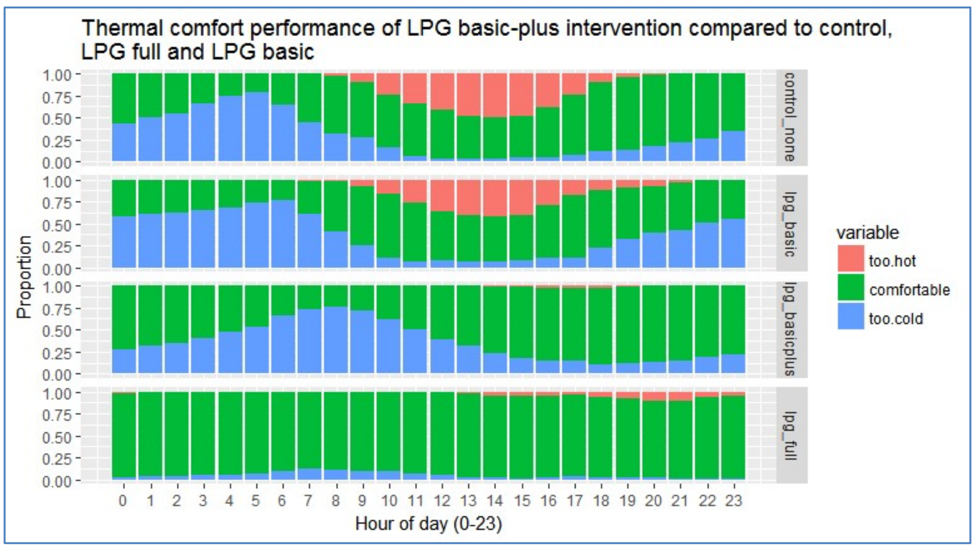

Figure 21 Thermal comfort performance of LPG basic-plus intervention compared to control, LPG full and LPG basic (Period: 11 Nov - 11 Dec 2016)

3.2.7. Kitchen King use in KwaZamokuhle (one year)

The inspection survey found:

- Boiler water seal damage (11 units, 32%)
- Cracks in body (8 units, 24%)
- Body burnt through (4 units, 12%)
- Internal barrier damaged (3 units, 9%)
- Ceiling damage where chimney passes through (2 units, 6%)

The narrative research also confirmed that, while the experience of the Kitchen King was typically positive, after one year of use (2 winters), significant cracking and water seal damage were experienced, along with other aspects such as the internal diagonal grid that did not last.

Although households are generally positive about the Kitchen King and its utility, the level of wear after one year is problematic.

Recommendations:

- To limit wear and tear, design modifications are required to the Kitchen King stove or an alternative product is required
- For any efficient coal stove, one would have to obtain thorough short and long term wear and tear test data before such stoves could be installed in a large number of houses
- For any model of stoves considered as an intervention, the emissions efficiency of worn stoves needs to be assessed in a laboratory, as it would defeat the purpose of rolling out efficient stoves if the efficiency degrades along with wear and tear
- Similarly, the indoor emissions of worn stoves would need to be assessed in a laboratory
- A consumables list and maintenance regime would need to be identified.

3.2.8. Kitchen King assessment: long-term

After more than 7 years since installation, 4 of the 9 stoves are no longer in use (no longer installed). However, the uninstalled stoves are not in a particularly bad condition and the reason for discontinued use was not ascertained. Speculatively, it may be related to closing the roofs to limit roof leaks; where the chimney went through the roof the opening was typically such that it would rain in. The 5 stoves that were still installed were evidently in regular use – many were warm or in use at the time of our visit on a windy September morning.

The majority of the small sample of active stoves displayed the following wear:

- refractory bricks in need of replacement (evidence of lack of maintenance)
- diagonal grids in the bottom of the primary chamber missing (a fairly inexpensive removable and replaceable part)
- air clutch levers missing
- boilers out of order
- cracked stove tops
- inner wall damaged or burnt through
- damaged oven latches
- missing ash trays

Two stoves were lit by householders, using coal, with some wood to facilitate ignition. One stove had an intact inner wall, and one had a damaged inner wall. Some smoke was visible 25 minutes after lighting the stoves in both cases, despite heavy wind. This observation may be meaningless –

laboratory testing (or on site testing) of emissions is required to obtain a meaningful understanding of emissions. The level of wear and tear noted after 7 years was substantial.

Our recommendations are similar to those regarding Kitchen King use in KwaZamokuhle:

- To limit wear and tear, design modifications are required to the Kitchen King stove
- Any efficient coal stove would have to be tested thoroughly for short and long term wear and tear before such stoves could be installed in a large number of houses
- For any model of efficient stove considered as an intervention, the emissions efficiency of worn stoves needs to be assessed in a laboratory, as it would defeat the purpose of rolling out efficient stoves if the efficiency degrades along with wear and tear
- Similarly, the indoor emissions of worn stoves would need to be assessed in a laboratory

4. Activity 4: Stakeholder communication

4.1. Methods

Stakeholder communication activities have been reported on in the month end progress reports.

4.2. Results

4.2.1. LSRG meetings

Three LSRG meetings took place in KwaZamokuhle (28 June 2016, 30 November 2016 and 23 March 2017).

4.2.2. MSRG meetings

One MSRG meeting took place, on 16 November 2016.

5. Activity 5: Analysis of 2016 air quality monitoring

5.1. Methods

These results are included in the issue 3 report which is published on the website at:

https://sites.google.com/site/offsetresearchpilot/home

See section 4.1.1 of issue 3 of pilot project report.

5.2. Results

5.2.1. Ambient air quality measurements

A more detailed discussion of the ambient air quality monitoring results for January 2015 to October 2016 is given in section 4.1.1 of the updated EOP Mod 1 report.

In short, the results indicate that:

- Particulate matter is the air pollutant responsible for the largest number of air pollution problems (as measured for example in exceedances of national ambient air quality standards) in the area
- Eliminating solid fuel used for space heating alone may not bring this area into compliance
- SO_2 concentrations are marginally out of compliance with national ambient air quality standards
- NO_2 concentrations are significantly below ambient standards and thus not problematic
- There is spatial variability in ambient air quality within KwaZamokuhle. The spatial variability is aligned to dispersion modelling results

5.2.2. Source apportionment and further analysis of ambient air quality monitoring confirms the importance of local sources.

The $PM_{2.5}$ and PM_{10} concentrations in Hendrina are significantly lower than in KwaZamokuhle.

In winter, ambient PM concentrations in KwaZamokuhle are more than double that of the warm seasons. This is also true for Hendrina, although the actual ambient concentrations are more than a factor of two lower than those recorded in KwaZamokuhle. It is likely that the use of solid fuels for space heating in KwaZamokuhle plays an important part in explaining these differences. However, exceedances regularly occur in warmer seasons, as well as adjacent to the areas where solid fuel burning is prevalent.

More detail is available in section 4.1.1 of the updated EOP Mod 1 report (issue 3).

5.2.3. KwaZamokuhle source apportionment

The winter source apportionment for KwaZamokuhle indicates that domestic coal burning is the largest source of $PM_{2.5}$ (63%).

The largest part of coarse fraction particulates (PM_{10} excluding $PM_{2.5}$) comes from dust sources. The combination of soil, unpaved roads and paved roads account for 42% course particulate mass. The next largest category is domestic coal combustion that accounts for 39% of the course particulate mass.

Additional information is available in section 4.3 of the updated EOP Mod1 report.

6. Activity 6: Preparation for informal housing pilot study

This requirement was removed in subsequent negotiations with Eskom due to the fact that it is not an extension of the earlier RDP-based activities. Sasol is currently conducting shack insulation testing and it was decided that duplication of research and development is unnecessary in this particular case.

7. Activity 7: Business process specification and data handover

7.1. Methods

Activity 7 had two objectives:

- Develop relevant business process specifications for implementation
- Improve the offset specifications and prepare for the lead implementations

The method followed was to submit and explain the PDD related business processes and experiences to Eskom staff in absence of contracted implementation contractors.

The two objectives are discussed below.

7.1.1. Develop relevant business process specifications for the implementation

The team investigated which methodology to use for the business process development. The tool used was MS PowerPoint due to usability afterwards. The analysis method used was the standard process input/output information flows with defined deliverables, auditable data requirements with identification of responsible entities. The level analysis was done in MS Excel down to 7 levels of detail where appropriate.

7.1.2. Improve the offset specifications and prepare for the lead implementations

Offset preparation and offset improvement deliverables and related data are to be made available to an entity to be contracted by Eskom to complete the lead implementation activities. Allowance must be made for regular interaction and explanations.

The implementation entity was not yet appointed by end March 2017 as envisaged. A handover work session thus took place with Eskom staff.

8. Activity 8: Compilation of project design document for lead roll-out in KwaZamokuhle

8.1. Methods

The consulting team formulated a project design document (PDD) based on the UNFCCC PDD template interpreted in the light of the Air Quality Impacts Protocol. The formulation of this document included extensive consultation with Eskom. This undertaking is the first of its kind in South Africa, and as far as we could determine, in the world.

Several decisions have been taken during this interaction that has determined the final form of the PDD document. These were that:

- Eskom will not obtain third party validation and verification if the Regulator does not require it
- The PDD will not contain an ex-ante calculation of the project impact because too many uncertainties still exist. The calculation of project impact will rather be presented in the first monitoring report

8.2. Results

The project design document was delivered as a separate document.

9. Activity 9: Project management

Ongoing project management activities have been reported in the monthly progress reports. A bi-weekly telephone conference took place between Eskom staff and team members to co-ordinate important activities.

10. Activity 10: Replacement of ceilings

10.1. Methods

Nova proposed to replace and assess ceilings in 20 houses in order to identify possible alternatives to Expanded Polystyrene Sheet ceilings. The team used the results of the energy inspection survey relating to observed damage and/or faults in houses to identify suitable participating households. The replacement specification was derived from the results of Activity 3.

10.2. Results

10.2.1. Assessment of alternatives

10.2.1.1. Problem description

During the pilot phase of the current project it became apparent that a significant proportion of intervention houses displayed water damage to the installation. This damage was mostly limited to excessive brown stain on ceiling boards, causes by water leaking on top and seeping through the polystyrene boards. Nova identified two major sources of this water, namely i. roof leaks and ii. condensation of indoor vapour against the cold roof metal. In cases where damage was severe Nova concluded that it was probably a combination of the two sources which caused the staining.

Roof leaks are caused by poor construction practices (e.g. not using rubber washers with roof fasteners) and insufficient maintenance (e.g. not sealing leaks resulting from normal wear and tear).

Condensation is caused by humid indoor air coming in contact with a cold surface – in this case the roof sheet at night. Because the polystyrene boards which were used to insulate do not sit flush with the roof sheets, a cavity is formed into which the humid air disperses and condensates.

10.2.2. Proposed alternative

The Nova Institute's research and development have focussed on the problem of water damage in retrofitted houses for some time before this request was formally submitted by Eskom. In order to combat roof leaks the implementer would have to install some form of water proofing or membrane on the exterior of the roof. This is not a desirable option as, firstly, it requires technicians to access the roof which often is in a poor structural state which can be exacerbated by stepping onto it. Secondly applying an external membrane contributes significantly to the future maintenance responsibility of the implementer. Combatting condensation is even more difficult as one would have to prevent the contact between humid air and the cold roof sheeting. The only effective way to do this is to seal off the roof with some sort of insulation on the underside.

In its search for alternatives (see 3.2.1) Nova could only identify one cost-effective, low-maintenance solution to address the challenges posed by excessive moisture in a typical structure. This system depends on Spray Polyurethane Foam (SPF) as insulation, which is waterproof, expansive (to plug leaks), and applied to the underside of the roof (preventing condensation). The system would include a standard gypsum board ceiling to act as fire barrier and finish off the installation.

The system specification was drafted as follow:

1. High density, two-component Spray Polyurethane Foam (SPF) applied to underside of roof, 25-30mm thick. The SPF product must:
    - Comply to all environmental standards set by South African legislation and contain only environmentally-friendly and low risk blowing agents
    - Comply to fair social responsibility standards
    - As a component of the ceiling system perform adequately in the required SANS tests
    - Be applied with an electronically governed spraying rig to assure accurate mixing rates and provide cut-out in case of anomalies
    - Be applied by an experienced and extensively trained service provider who can demonstrate:
        - A professional track record in applying SPF to a high standard
        - Extensive knowledge of SPF characteristics and performance
        - An intensive and integrative team member training plan
        - An excellent safety record
        - Formal quality assurance- and quality control plans

2. Rated waterborne intumescent paint coating applied to SPF by airless spraying
3. Gypsum ceiling system with steel brandering affixed to roof purloins directly under and at pitch of roof
4. EPS fire retardant finishing strips/cornices fixed to ceiling boards and not to walls
5. Non-acrylic ceiling paint for finishing

10.2.3. Installation

10.2.3.1. House selection

As the assessment of a ceiling alternative was focussed primarily on combatting water damage, Nova decided to rank houses in relation to the severity of the water damage identified during an installation assessment conducted during the preceding months. In addition to water damage Nova wanted to assess how the proposed alternative installation option would impact other issues identified such as ceiling boards moving/pulling out and cornices detaching from walls. Houses were ranked in order of specific damage identified by the assessor as follows:

1. Assessor indication: Installation assessment included "Ceiling badly stained by water"
2. Assessor indication: Installation assessment included "Ceiling slightly stained by water" as well as listed three other damage issues
3. Assessor indication: Installation assessment included "Ceiling slightly stained by water" as well as listed two other damage issues

Nova selected the 20 top ranked houses for alternative ceiling tests. The breakdown of intervention type was as follows:

Type	Count
Basic Electricity	5
Basic LPG	4
Full Electricity	3
Full Kitchen King	3
Full LPG	5
Grand Total	20

10.2.3.2. Implementation

Following the successful completion of the ceiling system design and fire tests Nova removed and recycled the polystyrene ceilings in the selected test houses. During December 2016 to January 2017 Nova installed the new SPF-based ceilings, conducted quality control and commenced comparative temperature measurements:

Project activities


10.2.3.3. Assessment

10.2.3.3.1. Resistance against water damage

Approximately one month after installation a Nova assessor inspected each test house and assessed the state of the installations. Apart from small construction errors like inefficient sanding of filler and/or nails protruding from the installation, the assessor found no trace of water damage to the installation. During the period of installation and the month thereafter KwaZamokuhle experienced significant rainfall which provides confidence that roof leaks had been addressed – at least in the short term. As households continued their usual in-house practices the assessment also implies that the problem with condensation had been addressed successfully in the short term. The long term effect needs to be monitored.

10.2.3.3.2. Resistance against other structural challenges

The Nova assessor found no instances of structural problems seen before with the polystyrene-based application. No boards moved and none of the finishing strips (no adhering to the boards rather than to the walls) detached. The robustness of the installation needs to be further assessed as time lapses.

Chapter 3 Findings and conclusions

In our opinion Eskom has the best chance of complying with all conditions set by the regulator if a project simultaneously complies with all the criteria below, namely, it should:

- Improve ambient air quality: This means that a net ambient air quality improvement should exist in the project scenario when compared with the baseline scenario
- Benefit households: Low-income households should, in addition to other benefits achieved, not pay more after the intervention for the same domestic energy utility (e.g. for cooking, space heating and water heating) than before the intervention
- Be cost effective to industry: Community air quality offsets should be more economical for industry than the alternative (e.g. immediate switch to new industrial process) and optimum value for the investment should be attained
- Have low risk for social instability: Risks should be managed by carefully designing and implementing the project in cooperation with households and other local stakeholders
- Be sustainable: A long term maintenance strategy is essential to protect Eskom's investment in improved air quality from decreasing, e.g. through new household formation, and wear and tear of interventions

Our evaluation of the pilot interventions in terms of these criteria are as follows:

1. Air quality impact

The emission from solid fuel use is derived from the mass of fuel burned and an emission coefficient for every pollutant and in principle should be calculated for every fuel-device-operation combination. Although some SO_2 is produced by domestic coal burning, and to some extent wood burning, the bulk of the air pollution impact resulting from domestic solid fuel use derives from emission or particulate matter – practically all of which is of the fine (<2.5 micron) size fraction. $PM_{2.5}$ is therefore the pollutant of concern that can be used to compare the expected impact of the different interventions.

The PM_{10} and $PM_{2.5}$ emission factors for coal and wood, that has also been used in the PDD and in the modelling done during the pilot phase is shown in Table 27.

Table 27: Emission factors for domestic solid fuel use

	Coal (g/kg fuel)	Wood (g/kg fuel)
$PM_{2.5}$	12.01	16.089
PM_{10}	12.91	17.3

Ignoring wood, focussing on coal only and taking the annualised coal use of 1206 kg per household-year (control group mean, post-post) – the resulting PM emissions that can be avoided are:

- 14.48 kg of $PM_{2.5}$ per year per household
- 15.57 kg of PM_{10} per year per household

Where solid fuel stoves are removed and replaced with LPG equipment (and in the absence of regression), the particulate matter emissions are avoided completely.

In the case of the Kitchen King stove, the mechanism through which the improved stove interventions are expected to work is not necessarily a reduction in fuel consumption, but rather more complete combustion of the fuel and therefore a lower emission factor for particulate matter.

The total volume of solid fuel burned in the town after a large scale stove swop implementation of the improved stove will therefore likely be the same for all practical purposes but the air quality may improve depending on the improvement in the emission factor. Over time, however, the improvement in the emission factor could decrease as wear and tear of the stove takes place.

The advantage resulting from the implementation of an intervention can be expressed as a reduction in emissions of pollutants (*p*) for a population (*Pop*) over any time period (*t*). For each scenario, the emissions can be calculated as follows:

$$E_{p,t} = \sum\nolimits_{f,p,t} Pop * prop_{f,t} * aveC_{f,t} * EF_{f,p}$$

Where:

E = The total emissions of pollutant *p* over period *t* from the study area (g)

Pop = The population size of the area for which the calculation is made (number)

$propf_{,t}$= The proportion of the population who use the fuel (proportion between 0 and 1)

$aveCf_{,t}$= The average fuel consumption per household of fuel *f* over period *t* (kg)

$EFf_{,p}$ = The emission factor for pollutant *p* from fuel type *f* (g/kg)

It is clear from the equation that emissions can be reduced in three ways namely:

1. by reducing the proportion of fuel users,
2. reducing the average fuel consumption per household, or
3. by reducing the emission factor.

The mechanism of the stove-for-LPG swop is to address the proportion of solid fuel users (since LPG has practically a zero ambient impact in terms of the pollutant of concern). The retrofit (independently of the energy carrier with which it is combined) reduces the average solid fuel consumption of households.

Regardless of whether a full, basic or basic plus insulation retrofit is used, the same results are expected in the short term when solid fuel stoves are removed and replaced with LPG equipment since without a coal burning device households are not expected to burn coal. However, the full retrofit outperforms the basic and basic plus in terms of the overall thermal improvement and as such it is expected to provide the best retention rate over the long term. It is also most beneficial to households in terms of the energy cost it takes to reach and maintain thermal comfort for each energy carrier.

To model the effects of interventions over time, one needs to estimate three functions:

1. The rate of change of the proportion of solid fuel users (e.g. the rate at which households who received the stove swop revert back to coal)
2. The rate at which the average fuel consumption changes
3. The rate at which the emission factor changes (e.g. the rate at which a high-efficiency stove loses its efficiency)

In a number of cases where households have uninsulated structures on the same stand as the retrofitted formal houses, they continued to use solid fuel stoves (or reverted to solid fuel stoves), which negated the removal of the stove in the formal house kitchen. This was however limited to households who had a shack or lean-to shack on the premises. Thus, in the case of households with "mixed structures", additional steps have to be taken in order to eliminate emissions from solid fuels. No current readymade solution exists to address this fully. It is foreseen that the development work currently in process to find a solution for shacks could contribute, in combination with the solution for formal houses, to a solution for mixed structures.

2. Benefits to households

2.1. Introduction

This subsection reflects on the question if households are in the same or in a better position after the intervention combination. Our assumption is that it cannot be expected of low-income households to fund higher energy cost to maintain their existing energy utility after the intervention. The pre-intervention utility and level of energy security therefore have to be matched as a minimum, and preferably be improved, in the post-intervention scenario at the same or reduced cost to households.

Based on the group interviews and open-ended in-depth interviews with all intervention groups, we believe that households indeed have the same or better energy utility after the intervention at the same or reduced cost than in the pre-intervention scenario. This is mainly due to the significant benefit the insulation renders in improving the thermal conditions inside the home. Both full and basic retrofit impacts meaningfully on people's experience of quality of life in their homes, with better indoor thermal comfort, less dust and feeling at home in a beautified structure.

The possible cost of maintaining interventions over the long term still needs to be determined.

The iButton temperature data and the results of the Detailed Energy Survey (DES) confirm that households in all intervention groups maintained and improved energy utility without incurring a discernible increase in energy costs. Basic retrofit houses were 8.98 to 12 degrees warmer inside than the ambient temperature at 5 am on winter mornings and were roughly 3 degrees warmer than control group houses. Full retrofit houses were 11.84 to 14.17 degrees warmer inside than the ambient temperature at 5am on winter mornings and were roughly 6 degrees warmer than control group houses.

In terms of the energy carriers provided by the project, both LPG and the Kitchen King were positively evaluated by households. No safety issues were reported in case of the LPG use and respondents were impressed by the speed and efficiency of cooking with their LPG stoves and that it contributes to heating the house in combination with the retrofitted insulation. The Kitchen King group enjoyed their stoves, although a number of minor design, as well as wear and tear issues were reported. The electricity subsidy group did not have to give up their current (original) coal stove in order to participate in the project. Thus, it was not possible to test as part of this particular assignment what the exact impact of an "electricity only" solution would be.

We conclude that all the tested intervention combinations are acceptable and desirable to end-users. The LPG stove and heater swop in combination with the full retrofit rendered the most benefits to households if all benefits are taken into consideration.

In our opinion the timing of the intervention combinations is important. The LPG group felt that the indoor temperature improved and that the LPG stove contributed to heating the house in combination with the insulation. These observations are understandable due to the pronounced difference between the pre- and post-intervention scenarios. If for instance a household receives a retrofit and keeps their coal stove and then have to change to LPG only a year later instead of immediately, the pre- and post-intervention experiences will differ, since the original coal stove in combination with full retrofit have the largest effect on indoor space heating. In other words, if a household is to swop their coal stove a year after they received insulation, they will experience less heat in the winter after the stove swop or have to invest more in electrical space heating to maintain the utility they had with the coal stove and full retrofit combination. The introduction of the retrofit intervention thus creates a "window of opportunity" to negotiate a stove swop with households. If the programme owner decides not to make use of this window of opportunity and to first do insulation and only later introduce stoves, we foresee a lower uptake as well as possible dissatisfaction with the stove swop. Project participants will most likely take what they had immediately before the intervention as reference point for comparison to their new situation.

2.1.1. Approach

There are various ways to approach the quantification of benefits to households as a result of the retrofit and stove swop interventions. Broadly the approaches can be divided as either being broad or focussed:

- **Broad approach** – estimating and aggregating all benefits as a result of the intervention e.g. health benefits as a result of improved indoor air quality and improved indoor temperature for all household members, adding all cost savings, as well as the initial investment in the structure, assessing the impact in term of a comprehensive benchmark such as the United Nations Sustainable Development Goals (UN SDGs) or the South African National Development Plan (SA NDP) targets, including jobs created, etc.
- **Focussed approach** – focussing on specific key indicators purposely chosen to assess the impact on participating households

For the purpose of this report, we shall take the focussed approach. In our opinion the intervention can only be justified as being "beneficial to households" if the households concerned have the same or better utility post intervention at the same or reduced cost than in the pre-intervention scenario. In other words, even if there are significant advantages such as the investment made in the dwelling structure, as well as long term health benefits, it cannot be expected of low-income families to have the cash flow to fund higher energy cost to maintain their existing energy utility. The pre-intervention utility and level of energy security therefore have to be matched as a minimum, and preferably, be improved in the post intervention scenario at the same or reduced cost to households.

If this reasoning is accepted, then the question arises which indicators are the most appropriate to compare pre- and post- energy utility, energy cost and energy security? We would argue that there is no single indicator that can measure pre- and post- energy utility, cost and security all at once. Comparisons between the pre- and post-intervention scenarios are complex. Energy usage patterns and energy utility of low-income households are not only influenced by subjective human determinants and preferences but also by resource accessibility, availability and affordability. This makes pre- and post-intervention *energy-utility-versus-cost* comparisons challenging and even more so in the low-income context where the suppressed demand is present because the immediate availability of cash or fuel influences energy expenditure.[7]

The complexity lies not only in the measurement of domestic energy utility or cost as reported by households, but even more so in the interpretation of the relationships between these aspects pre- and post-intervention. Thus, a case has to be built by considering all information available in order to judge the particular benefits to households per intervention type.

2.1.2. Method

We propose the following method to build a complex case to establish the particular benefits to households as a result of the interventions tested, as well as to determine if the removal of the coal stove can be ethically justified:

Step 1: Consider the post-intervention experiences of households

Step 2: Evaluate the post-intervention situation for the following relevant indicators:

- Fuel use and cost per season
- Thermal effects of the intervention combinations

Step 3: Model the thermal improvement benefit

> This is highly dependent on assumptions on how much space heating can and should realistically take place in the project scenario. The problem is acute as a result of the reality of poverty and the resulting phenomenon known as "suppressed demand". The CDM approaches these types of dilemmas by calculating the level of suppressed demand, often by establishing a minimum service level, based not on the reality of present sub-standard level of energy use due to poverty but on the assumption that poor people have fundamental human needs and therefore have the right to a minimum amount of energy to actualise their needs by having a minimum quantum of energy for lighting, cooking, space heating, heating water for bathing, communication, etc.

Step 4: Rate the interventions in terms of its benefits to households

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[7] Please refer to the paragraph on *Factors influencing the choice and cost of energy carriers* for a more detailed discussion of this topic.

2.1.3. Step 1: Post-intervention experiences of households[8]
From the qualitative results in presented in Chapter 21.3 page 9 we found the following.

Both the full and basic retrofit groups reported that they experience substantial temperature improvements. Other benefits mentioned included less dust, less staining from rust leaking into furniture and bedcovers and aesthetic value, as well as creating the sense of “feeling at home”.

Both full and basic retrofits received positive evaluations: it is not possible to detect a distinct difference between the two types of retrofits from people’s perceptions, bearing in mind that each respondent experienced only the one or the other.

LPG was very popular: it is quick and clean, according to respondents the gas stove also contributes to heating the house in combination with the improved insulation. No safety issues were reported. The fact that, unlike a coal stove, it can be switched off when the cooking is done saves money. The gas stove also functions as a heater, in combination with the insulation it provides enough heat in most cases and the heater itself is only used when it is very cold.

In the group discussions, the general opinion was that coal is expensive and some observed that the use of LPG is cheaper than coal.

Some regression of LPG households to coal use took place where there were non-insulated structures on the same site as the participating household. Motivating factors may include the need for more extreme heat by some households or other factors. Savings that could be realised as a result of having the electricity voucher was used not only to fulfil in the demand for more domestic energy but often also to buy a variety of other things.

There are very few indications that residents take ownership of the improvements, except in the group interviews, where a strong sense of ownership manifested.

People commented on how beautiful the ceilings make their houses. It has gone a long way to increase the sense of the house as “a place to feel at home”, which is a deep need in these communities.

Trust in ESKOM and Nova is at a high level.

We conclude that:

- Both the full and basic retrofits are desirable to the participant end-users
- The perception is generally that LPG improves cooking utility at a reduced cost and there is no indication that thermal comfort comparable to the pre-intervention scenario was more expensive to reach in the post intervention scenario for LPG users
- The perception is generally that the Kitchen King improves cooking and water heating utility. In combination with the retrofit it also contributes to thermal comfort in winter times. It is interesting that some households reverted back from electricity to coal for utilities such as heating of bath water

[8] Refer to: *Overview of qualitative research so far*, presented by AS van Niekerk, October 2016: The report summarises three research actions done between September and October 2016, namely, group interviews, a snap survey of 120 households where interventions were done and a revisit to 9 households that received LPG but still reported coal use. Reports for each of these three actions are also available.

- There might be a minority of households that will require fairly extreme heat (for example to keep infants or elderly people warm) which could be more difficult to affordably sustain by LPG in winter even in the context of retrofitted insulation
- Space-heating in non-insulated environments such as in second or mixed structures tend to favour coal use
- The present high level of trust in Nova and Eskom provides a window of opportunity for the development of a long term maintenance strategy with households - not only to maintain the interventions but also to maintain the good relationship with the community

2.1.4. Step 2: Evaluate the post-intervention situation

2.1.4.1. Fuel use and cost per season

The results of the Detailed Energy Survey and the coal measurements show that coal use did not decrease in the Kitchen King group; coal use in the basic retrofit and KK combination group even increased in the post-post intervention scenario with about 12% and the full retrofit group and KK combination with about 20%. This data corresponds with remarks households made in the group interviews, namely, that some Kitchen King households stopped heating water for bathing in the electric kettle and rather used the KK stove. The combination of cooking-, space heating- and water heating utility, now in a more thermally comfortable environment because of the retrofit, has proved to be popular and enforces the use of coal in the KK group.

The basic retrofit and electricity group had about a 50% reduction in coal use and the full retrofit and electricity group roughly a 44% reduction (compare Table 3: Summary of self-reported winter monthly coal use (kg) as captured in the Detailed Energy Surveys between 2014 and 2016).

The stove swop is by far the most effective in eliminating coal with an approximately 90% reduction for the basic and LPG group and a 97% reduction for the full and LPG group if the impact of coal use in adjacent informal structures is avoided.

The average winter cost per month calculated for all energy carriers as reported by households only increased for the coal basic group from R436 in the pre-intervention scenario to R622 in the post intervention scenario.

It is interesting to see that several of the control group households reverted to wood in the post-intervention scenario.

Self-reported cost estimations must be interpreted with caution. During the fieldwork it is always emphasised that participation in the survey as well as answering individual questions are voluntary. It is noteworthy that more households choose not to answer questions related to cost estimates than other types of information requested. Furthermore, there seems to be greater variability in energy expenditure in the low-income context where suppressed demand and availability of cash for energy is more variable than in a typical middle or high-income context.

What is important is to note that there is no indication from these reports that a sudden increase in energy cost was incurred by households as a result of the interventions. This observation is confirmed by the feedback of the qualitative interviews where respondents were more inclined to report cost savings (particularly in the case of LPG) rather than an increase in cost for energy.

2.1.4.2. Thermal effects of the intervention combinations

The indoor ambient temperature delta at 5am is presented in Table 28.

Table 28: Indoor temperature deltas at 5 am compared with control group

	Post Intervention				Post Post Intervention			
Intervention Type	Mean Δ (°C)	95%CI	n	Difference Δ temperature with control group(°C)	Mean Δ (°C)	95%CI	n	Difference in Δ temperature with control group(°C)
coal basic	11.6	(11.21, 11.99)	280	4.99	11.45	(10.07, 12.83)	40	4.31
coal full	11.98	(11.58, 12.38)	245	5.37	12.22	(11.39, 13.05)	55	5.08
control none	6.61	(6.23, 6.98)	245	0	7.14	(6.11, 8.17)	23	0
elec basic	10.64	(10.21, 11.06)	250	4.03	12	(10.65, 13.36)	34	4.86
elec full	13.55	(13.02, 14.08)	200	6.94	14.17	(12.92, 15.41)	48	7.03
lpg basic	8.98	(8.55, 9.42)	175	2.37	9.22	(8.59, 9.85)	113	2.08
lpg full	11.84	(11.35, 12.33)	280	5.23	13.7	(12.86, 14.54)	84	6.56

Basic retrofit houses were 8.98 to 12 degrees warmer inside than the ambient temperature at 5 am on winter mornings and performed 2.08 - 4.99 degrees better than control group houses. Full retrofit houses were 11.84 to 14.17 degrees warmer inside than the ambient temperature at 5am on winter mornings and performed 5.08 - 7.03 degrees better than control group houses.

The results of the indoor temperature measurements presented in Chapter 22.2.4 show how the interventions increased the time in thermal comfort by protecting against extremes of both heat and cold. On the whole the full retrofit results in the largest increase in the proportion of observed time spent in thermal comfort in both winter and summer. The intervention types where coal is still being used have the largest proportion of time in thermal comfort. The one part of the day where there is less thermal comfort is mid-day where the uninsulated structure gains heat rapidly. This heat is quickly lost however so that by later afternoon the uninsulated structures are again thermally uncomfortable.

2.1.5. Step 3: Model the thermal improvement benefit

Numerous complex factors influence the choices of households for a particular energy carrier. In a context of poverty factors such as accessibility, affordability, availability and energy security are even more substantial than in middle income or rich areas.

The qualitative research done highlights "what lies behind peoples' behaviour and choices"; we are of the opinion the following factors are noteworthy:

- Traditional versus modern usage patterns: socialising in front of the coal stove and cooking dishes for larger groups versus the need for clean efficient and fast cooking
- Human development phase of household members: elderly people and infants need more "excessive heat" and parents with school age children appreciate utilities with speed in the mornings before school
- Behaviour: leaving doors open, not repairing windows, closing windows at night, etc.
- Education and awareness: knowledge of the health risks associated with ambient and indoor air pollution, etc.

- Personality, personal preference and personal responsibilities: being an early adaptor or being inclined to stick with traditional cooking methods, etc.
- Other: Taste of food, type of food, social events, etc.
- Taking ownership of and the capability to maintain interventions

The quantitative research done in this pilot highlights "how widespread a particular choice for energy carrier or utility is and what the mean and median figures for particular relevant indicators are". We are of the opinion the following factors are noteworthy:

- Demographic factors: number of household members, age, physical location, thermal performance of dwelling, etc.
- Energy poverty: accessibility, affordability, availability, energy security (e.g. power outages, etc.)
- Services and infrastructure: Factors influencing thermal comfort include internal heat sources, size of the dwelling structure, location, orientation, shade, thermal mass of the structure, insulation and ventilation (humidity & activity)

Furthermore, additional macro anthropogenic and meteorological factors are to be considered such as:

- Climate, seasonality, weather patterns
- Political context (lack of services, jobs, etc.)

In measuring the impact of an intervention combination such as the retrofitting with improved insulation in combination with a stove and heater swop, one approach is to try and measure all factors that influence the pre- intervention and post-intervention scenarios and to then make a conscious effort to measure and integrate all of the relevant factors mentioned above. However, it is not only a very expensive undertaking, but also extremely difficult, since keeping track of the behaviour of several residents of a house in combination with complex meteorological and other factors, is almost impossible. Another approach, particularly appropriate for low-income contexts is to define a minimum service level to meet basic human needs as a baseline, and then to see what the impact of the project intervention is in bringing a household closer to that service level. The CDM guidelines on the consideration of suppressed demand in CDM methodologies (Version 02.0) states that a suppressed demand situation is applicable when a minimum service level to meet basic human needs was unavailable to the end user of the service prior to the implementation of the project activity.

In this pilot study, Acceptable Indoor Temperature (AIT) range[9] is such a minimum service level. The quantification of the value of the thermal improvement of the basic and full retrofit is theoretical in

[9] The applicable range of indoor temperature that is classified as comfortable is calculated as follows.
For waking hours (defined as 6am to 10pm), indoor thermal comfort is achieved at 18.9°C + 0.255*ambient temperature +/- 3.5K, lower limit 17.5C, upper limit 29.5°C. For sleeping hours (defined as 10pm to 6am), indoor thermal comfort is achieved at 18.9°C + 0.255*ambient temperature +/- 3.5K, lower limit 16.0C, upper limit 29.5°C.

as far as that there are not really any realistic chance that someone will attempt to achieve similar thermal benefits through constant burning of coal or heating with LPG in the project context. Perhaps maintaining the temperature with an electrical air conditioner renders a better comparison, but once again it is not a real option for project participants. However, it can be argued that the temperature extremes and lack of thermal comfort in non-insulated houses are severe and the fact that poor people do not have the financial capability to change their situation, cannot be used to deny them the value of the temperature improvement as a result of the better insulation. By not having properly insulated houses, the cost of reaching better thermal conditions inside is currently fully on the shoulders of these households. Even after the insulation households are far from permanently being in an AIT-range. Therefore, we would argue that it is conservative, for the purpose of making a theoretical comparison, to quantify the benefit by calculating the price of the electricity it would take to run an air conditioner permanently per house to attain a similar temperature benefit.

The cost of retrofitting their homes with insulation is currently one of the barriers to low-income households to make progress on the energy ladder towards cleaner energy options. If there were no barriers, it can be assumed that households will eventually move towards either an electricity or LPG solution.[10]

2.1.6. Step 4: Rate the interventions in terms of its benefits to households

Our evaluation in the light of Steps 1-3 is that the pilot intervention combination with the most benefits to households is the LPG stove swop and heater in combination with a full retrofit. Importantly, the full retrofit is best at improving both how long the house is too cold or too hot (decreased duration of thermal discomfort), and by how many degrees the house is too cold or too hot (decreased depth of thermal discomfort).The modelled degree-hours under thermal comfort for the basic retrofit with the LPG stove swop was only 94.5% of that modelled for the control group (14671 / 15516; see Table 13). In our opinion this can hardly be seen as a good enough improvement in thermal comfort to ensure the sustainability of the intervention.

10 https://www.google.co.za/search?q=energy+ladder+images&tbm=isch&imgil=g3kuQkm29X4Q8M%253A%253BRQbfHEb58xgu-M%253Bhttp%25253A%25252F%25252Fwww.leslieforman.com%25252F2009%25252F12%25252Fcow-dung-poverty-and-microfinance-in-inner-mongolia%25252F&source=iu&pf=m&fir=g3kuQkm29X4Q8M%253A%252CRQbfHEb58xgu-M%252C_&usg=__KYZUZaI_752p5MByS_0RDHygkQo%3D&biw=1280&bih=648&ved=0ahUKEwiV0sfs7JHTAhXsA8AKHTA4APIQyjcIOg&ei=fUPnWNWfH-yHgAaw8ICQDw#imgrc=g3kuQkm29X4Q8M:&spf=191

3. Cost effectiveness

3.1.1. Cost per kg coal removed
One approach towards measuring the value for the industry investment is to express the cost as Rand per kilogram of reduction in coal use (also R/PM2.5 and/or PM10 removed). The optimum investment has to be the least cost investment that also complies with all other criteria.

A basic plus retrofit and stove swop cost approximately 40% less than a full retrofit and stove swop. The cost included in this calculation includes the retrofit bill of materials (assuming SPF rather than EPS) and labour for a non-extended RDP dwelling (assuming an implementer mark-up), LPG starter pack and LPG training. The cost excludes potential electric work, certificate of compliance and local management unit costs.

The cost estimate is not shown here, considering that this document may be published during the tender process for implementation activity. The cost estimate will however be made available to the client.

Even though the sample for LPG households in KwaZamokuhle is small, the association between regression to coal use is linked to the existence of non-insulated extensions or structures in addition to the particular household's insulated RDP and is statistically significant. The same is not true for the level of retrofit.

3.1.2. Cost and utility
The qualitative results show that households preferred LPG over electricity for cooking and water heating. Regarding space heating, feedback is more ambiguous with LPG space heating sometimes noted positively in comparison to electricity. No household stated a preference for electric space heating over LPG space heating though.

Electric heating could be in the same or a different room or structure as the coal stove. The study group is fairly small; thus extrapolation is speculative.

At face value, retrofit insulation increases the prevalence of electric heating – even for households that use Kitchen Kings or coal stoves. Hypothetically, this may suggest that with insulation, electric space heating becomes more effective in addressing household requirements.

LPG households typically indicate that their preferred space-heating device is the LPG heater (refer validation survey). Hypothetically, this could imply that electric heaters are used for some specific spaces or objectives.

Table 29 shows the percentage of households that use electricity as part of the space heating mix

Table 29: percentage of households that use electricity as part of the space heating mix

Intervention type	Pre	Post	Post Post
lpg basic	37.50	47.37	52.94
lpg full	25.00	50.00	36.84
coal basic (KK)	20.00	47.06	35.00
coal full (KK)	21.05	40.00	31.58
elec basic (coal stove)	23.53	45.00	65.00
elec full (coal stove)	7.14	47.37	57.89
control none	42.86	47.06	50

Group interviews indicate that LPG is considered better than electricity for cooking and water heating. Households also mention that when you have cooked with LPG, the house also heats up. However, comments regarding space heating using LPG versus electricity were not prominent. The same pattern is noted in individual comments: LPG is better than electricity for cooking, while for space heating the comparison is not typically made. During the validation survey, LPG households typically indicated that space heating with LPG is cheaper than with electricity.

Space heating should be made redundant as far as possible: electric heating and LPG heating are both very expensive relative to coal if measured in R/joule.

4. Social risk and safety

4.1. Safety of LPG use

Safety training and visits were conducted at LPG houses. From the LPG safety officers visits and inspection surveys (where questions regarding gas leaks and gas accidents were specifically included), no accidents or gas leaks have been recorded after the second winter of use. It is clear that project participants understand how to use LPG and that it is understood that children should not use LPG.

There is a general public perception of LPG as being unsafe, for instance in the internal straw poll conducted by Eskom RT&D. The existence of bodies like LPGSASA (LPG Safety Association of South Africa) is evidence that real and perceived risk should be addressed. Before issuing LPG equipment to households, the households were first trained. After issuing the LPG equipment, intense safety surveying was conducted for the first 3 months (visits every 2 weeks by a safety officer), followed by lower intensity activity for another 6 months (visits once a month). The officer interviewed household to ascertain whether any incidents occurred, and reinforced safe use principles. After winter 2016 an inspection survey was conducted in 37 of the 40 LPG households – after more than one year of use (two winters). Specific questions were included regarding LPG leaks, and LPG accidents. No household reported either a leak or an accident.

From group discussions and individual open question answers it may be noted that there is an underlying understanding in the intervention group that LPG is hazardous if used by children or used incorrectly, and that correct use is safe.

4.2. LPG heater use impact on air quality acceptable

Eskom RT&D tested the impact of prolonged LPG heater use indoors (with windows and doors closed) at different settings. The report indicates that using the LPG heater adds CO and NOx to the indoor environment, but that both remain well within ambient air quality standards. Particulate matter concentrations did not seem to be affected by LPG heater use.

4.3. SPF ceiling system safety

The SPF ceiling system (including gypsum ceiling and intumescent paint on the underside of the SPF, the SPF being sprayed onto the underside of the corrugated iron roof) was tested for flame spread as prescribed by SANS. A B1 certification was obtained, implying that no flame spread occurred.

4.4. EPS wall cladding safety

EPS is a non-flammable material. In addition, the EPS cladding is covered by 20mm thick non-flammable cementitious plaster on the outside. Fire spread tests were not deemed necessary in this regard.

4.5. SPF wall cladding safety

SPF wall cladding is covered by 20mm thick non-flammable cementitious plaster on the outside. Fire spread tests were not performed.

5. Sustainability

Long term impact maintenance of the air quality improvements depends on mainly two factors: the robustness of the technical interventions and the proper corrective measures in case an intervention is not maintained or used, e.g. by new household formation, wear and tear, LPG that is not available, or other events.

5.1. General observations

Good progress has been made to optimise the robustness of the technical intervention, as discussed in this report. The following general observations regarding the technical aspects of sustainability can be made:

- Replacing EPS ceilings with SPF ceiling systems is likely to solve the technical issues relating to the ceilings, including brown stains and movement of EPS panels. Initial inspection confirms that the SPF ceiling system does not show brown stains or movement
- SPF ceiling performance in winter, specifically with LPG in mid-winter, is not yet tested but is expected to be sufficient, based on Kwadela data (mid-winter, no stove swop) and KwaZamokuhle data (summer, LPG)
- Kitchen King wear and tear is problematic after two winters of use, and also after 7 years of use. Any alternative product or design change would have to be tested for real life wear and tear over an appropriate period of time before a final artefact is adopted

5.2. Kitchen King survey in KwaZamokuhle

Of the 40 Kitchen Kings installed in KwaZamokuhle, 34 units were inspected after approximately 1 year (2 winters) of use. The inspection survey found:

- Boiler water seal damage (11 units, 32%)
- Cracks in body (8 units, 24%)

- Body burnt through (4 units, 12%)
- Internal barrier damaged (3 units, 9%)
- Ceiling damage where chimney passes through (2 units, 6%)

The narrative research indicated that, while the experience of the Kitchen King was typically positive, after one year of use (2 winters), cracking and water seal damage were experienced, along with other aspects such as the internal diagonal grid that did not last.

Although households are generally positive about the Kitchen King and its utility, the level of wear and tear after one year is unacceptable.

5.3. Kitchen King survey near Standerton

To assess long term wear and tear, a farm near Standerton where several Kitchen King stoves were installed in late 2008 (reportedly) was visited. The stoves were installed in farm labour houses, noting that the operators of the stoves are therefore not the owners of the stoves. Nine houses were visited.

After more than seven years since installation, the following is noted:

- 4 of the 9 stoves are no longer in use (no longer installed). However, the uninstalled stoves are not in particularly bad condition and the reason for discontinued use was not ascertained. Speculatively, it may be related to closing the roofs to limit roof leaks, as where the chimney went through the roof, the opening was typically such that it would rain in
- The 5 stoves that were still installed were evidently in regular use – many were warm or in use at the time of our visit on a windy September morning

The majority of the small sample of active stoves displayed the following wear and tear:

- refractory bricks in need of replacement (evidence of lack of maintenance)
- diagonal grids in the bottom of the primary chamber missing (a fairly inexpensive removable and replaceable part)
- air clutch levers missing
- boilers out of order
- cracked stove tops
- inner wall damaged or burnt through
- damaged oven latches and missing ash trays were also noted

Two stoves were lit by householders (using coal, with some wood to facilitate ignition). One stove had an intact inner wall, and one had a damaged inner wall. Some smoke was visible 25 minutes after lighting the stoves in both cases, despite heavy wind. This observation may be meaningless – laboratory testing (or on site testing) of emissions is required to obtain a meaningful understanding of emissions. The results of these laboratory tests on an old Standerton Kitchen King stove will be given in a separate report.

The level of wear and tear noted after seven years was substantial. Any alternative product or design change would have to be tested for real-life application over an appropriate period of time.

The required materials for maintenance would have to be stocked locally, and periodic inspection may be required in order to ensure continued effectiveness in terms of emissions.

5.4. LPG houses in KwaZamokuhle

Of the 40 LPG stoves and heaters installed in KwaZamokuhle 37 units were inspected after approximately 1 year (2 winters) of use. The inspection and data capture was questionnaire assisted (inspection survey). The following observations can be made:

- The LPG equipment did not show substantial wear and tear to hoses, regulators, cylinders, clamps and actual equipment after one year. In similar vein, the snap survey and group sessions did not indicate concerns relating to LPG equipment wear and tear
- Wear and tear of insulation components show that EPS ceilings are challenging while EPS wall cladding remain acceptable
- Regression will need to be monitored
- Accessibility of LPG would need to be assessed and addressed accordingly
- During the second winter of use (2016), households had to obtain LPG without distribution assistance. As evidenced by remarks in the narrative research, at least some households made a significant effort (for instance keeping each other informed when LPG is available) in order to successfully obtain LPG
- After the winter, households in KwaZamokuhle specifically approached the Local Project Coordinator to intervene regarding the local Total garage not accepting Afrox cylinders for exchange, and regarding the prices of a particular local dealer
- Wear and tear of LPG equipment are positive after 2 winters of use which indicates a positive sustainability expectation

5.5. Insulation retrofit component

To determine the wall cladding condition, 54 of the 60 full retrofit households in KwaZamokuhle were visited after 1 year (2 winters). To determine the ceiling condition, 109 of the 120 retrofit households were visited. Each insulation component was inspected systematically. The inspection and data capture were questionnaire assisted. The EPS ceilings exhibited numerous problems, including:

- Brown stain (slight) – 34%
- Brown stains (badly stained) – 13%
- Ceiling board moved and left open hole(s) – 36%
- Cornices came loose from wall or ceiling – 28%
- Ceiling strips came loose – 14%
- EPS Board fell out – 1%
- No damage – 23%

It can be concluded that a more robust ceiling solution should be developed, that can withstand poor roof maintenance (leaks) and other moisture related problems. One possibility is to investigate affixing cornices to the ceiling, and not the walls.

5.6. External wall cladding and draft proofing (full retrofit)

The EPS wall cladding (with covering plaster) exhibited fewer problems than the ceilings, including:

Findings and conclusions

- Slight damage to outside insulation or plaster – 19%
- Badly damaged outside insulation or plaster – 7%
- Damage to dark paint (north wall) – 19%
- Problem with draft proofing – 2% (1 instance)
- There were no issues noted with the Trombe wall

Interestingly, the EPS that is affixed to the wall did not exhibit shrinkage related issues (in contrast with the EPS that is placed in the ceiling), probably because the EPS wall cladding remains "stretched" due to the manner it is affixed to the existing structure. In contrast, the EPS ceiling panels fit into brackets that would not inhibit shrinkage.

It can be concluded that the EPS wall cladding and draft proofing can be considered for lead roll-out as is, from a wear and tear perspective.

Chapter 4 Recommendations

Based on the main findings and conclusions of the EOP Mod3 phase, the results of the first phase of the pilot project and previous experience in similar projects we make three recommendations for the lead implementation:

- Swop the coal stove for LPG stove and heater
- Implement full retrofit
- Provide good quality LPG equipment

We can make no recommendations about an intervention where electrical appliances are swopped for solid fuel burning stoves because this has not been tested. The consulting team's philosophy has always been that interventions need to be developed with end users, subject to in-use evaluation by a group representative of end-users before large scale implementations.

1. Answers to TOR questions

The EOP Mod3 contract extension request and the subsequent proposal by NWU contained a series of questions to be answered during the execution of the work. These questions are:

- What retrofit combination should be used for the large-scale roll-out?
- What is a suitable solution for the brown mark staining of the EPS ceilings?
- Is the LPG household energy cost the same or lower than before the intervention?
- Can the LPG intervention be recommended going forward?
- What risks should be avoided/contained going forward?

The findings are presented below as responses to each question:

1.1. Which retrofit combination should be used for the large-scale roll-out?

When the energy carrier provided is LPG, we recommend installing a full retrofit. The premise of the intervention, which has not been falsified to date, remains that households will relinquish their space-heating source (a coal stove) in exchange for an inferior or less affordable heating source (an LPG heater) only if the need for space heating can be drastically reduced. We have already observed cases where people reverted back to coal because they felt too cold. For LPG users, the full retrofit provides much better protection against temperature extremes compared to the basic retrofit where practically all the mornings are too cold.

1.2. What is a suitable solution for the brown mark staining of the EPS ceilings?

The inspection showed that there were numerous problems with the EPS ceilings that were more serious than the brown marks. An SPF ceiling system including a gypsum ceiling and intumescent paint will solve the brown marks as well as the other problems related to the EPS ceilings such as the moving of the boards and cornices coming loose.

1.3. Is the LPG household energy cost the same or lower than before the intervention?

It is reported as lower by the households in individual and group session feedback. There is no indication in the household survey reports that it was more expensive to maintain pre-intervention utility. However, the exact pattern of space heating utility changes, since a coal stove provides intensive heat for the peak burning period whereas the full retrofit leads to overall thermal improvement, as well as the ability to heat the house to thermal comfort level with less energy. A few households that used the LPG heaters regularly did report an increase in cost. Our interpretation when all data is considered is that the households did not pay more for the same or better utility in the post intervention scenario.

1.4. Can the LPG intervention be recommended going forward?

We recommend that LPG be used in future implementations. The results from the qualitative investigations as well as from the structured interviews all show that end-users experience the LPG in a very positive way. No safety concerns were observed. LPG is economical as source of cooking energy and with the full retrofit the occasions on which heating is needed is reduced dramatically.

Since the households are electrified already, one can view LPG and coal as one of a number of energy options that the households have available. In the light of this fact, the use of LPG in future implementations must be evaluated on a calculation, not of the risk that LPG will not be available for a certain period in future, but of the risk that LPG and electricity will become unavailable at the same time – thus leaving households without a form of cooking energy. LPG can therefore be used if Eskom has the expectation that over the next few years LPG will be available most of the time (and not all this time).

LPG can be implemented on conditions that certified equipment be used and proper safety training with initial usage control and inspections are implemented as has been done in the pilot phase. We recommend that on-going LPG equipment safety inspection be done, at least initially and that support structures be put in place to assist households with maintenance of equipment.

1.5. What risks should be avoided/contained going forward?

We identified the following risks:

1. The household qualification criteria need careful consideration and clear communication
2. Implementation teams need to be well trained and managed
3. Quality assurance, control and audit require focused attention
4. Consistent messages to manage expectations of all relevant stakeholders
5. The time-pressure on implementation increases the risk that interventions that are not thoroughly tested will be implemented at scale and may fail at scale
6. We still need an expert opinion on the risks associated with fire if SPF is used
7. The risk that interventions are not maintained over the longer term must be addressed

Risk numbers 1 and 4 are identified based on observations of other similar processes in South Africa in general and in other projects where we worked and from our experiences in the stakeholder communication process. This risk specifically relates to raising of expectations that may not be met later.

Risk number 2 is identified based on our experience during the construction phase

Risk number 3 follows from the fact that compliance-grade monitoring is required for this project. This is further demonstrated by the inspection survey that shows quality problems are present even where there was fairly intense management. During the pilot phase the interventions were relatively unknown but the scale was small; as the implementation programme progresses, more experience will be gained but the scale will increase dramatically. The quality assurance and quality control system must grow in efficiency in pace with the growth in scale

Risk number 5 is identified based on the experience of the intervention development process in this and other similar projects where unexpected outcomes to interventions occur frequently. This is to be expected because the inventions are complex (as opposed to complicated). We recommend that Eskom should remain committed to the phased approach (albeit fast-tracked) and retain interaction with end-users in every phase of the project.

2. Recommendations for the intervention combination

Household-based air quality offset interventions are still in a development phase. Various aspects need further development and should be factored into the lead implementation design. The retrofit without a stove swop is the intervention that has been tested on the largest scale (by Sasol in Kwadela). The combination of insulation with a stove swop has been tested on a smaller scale during the pilot phase of the current project.

It is of paramount importance that further development of intervention options should take place in a programme of activities with a phased approach moving from pre-feasibility studies, through feasibility testing, to piloting and eventually to large scale roll-out and long term maintenance. This should be done especially with a view to communities where solid fuel burning is not the main source of air pollution and where solid fuel use takes place in informal houses where the current intervention options cannot be implemented.

A formal AQ offset funnel must be developed and the likes of Eskom and Sasol can work together in a symbiotic relationship to eliminate duplication and to manage the development cycles.

2.1. Do a stove swop

We recommend the total removal of the existing solid fuel stoves for the large scale offset implementation.

Where the solid fuel burning stoves are removed from households where they were in active use a reduction in PM_{10} and $PM_{2.5}$ from these household emissions can virtually be guaranteed. The only possible exception is where the household acquires another solid fuel burning stove. However, the ceiling installed as part of the intervention makes it difficult to install a new stove since there is no hole for the chimney. This presents a barrier to reintroduction of solid fuel use.

The one-year follow-up of the LPG households showed that approximately 80% (32 out of the 40 households) continued using the LPG stoves for the second winter. From the 7 out of 40 households that re-introduced solid fuel use 6 introduced it to the lean-to informal structure. In the case of one household the owner passed away, and the new owners did not have LPG equipment and thus installed a coal stove.

It is important to monitor what the annual rate of regression is over the longer term.

2.2. Do the full retrofit

We recommend installing the full retrofit because of a substantial improvement in thermal comfort (expressed both as the proportion of time spent in thermal comfort and the absolute minimum and maximum temperature difference at the coldest time of a winter day or the hottest part of a summer day). A higher indoor temperature of 5-7 degrees Celsius above that of the control houses was recorded during cool periods.

2.3. Provide quality LPG equipment

We recommend a stove swop with an SABS approved LPG 4 plate stove with oven and an LPG heater can be considered for the large scale roll-out. The results from the follow-up interviews showed that safety concerns were addressed successfully.

2.4. Electrical stove swop option?

An electrical stove swop intervention has not yet been piloted and should be expedited should Eskom top management prefer such an intervention due to forecasted excess generation capacity. The implications of this approach for the additionality of the interventions need to be considered. We strongly recommend that any new intervention be tested thoroughly before any large-scale intervention starts.

3. Recommendations for large scale roll-out

The pilot and lead implementations have been structured to give a better understanding of air quality offsets as well as to reduce the risk for the large-scale rollout. In the subsections below we provide a number of key factors Eskom Steerco should consider in the roll-out of the large-scale community air quality offset programme:

3.1.1. Apply a phased approach

Household-based air quality offset interventions are still in a development phase. Various aspects need further development and should be factored into the lead implementation design. The retrofit without a stove swop is the intervention that has been tested on the largest scale (by Sasol in Kwadela). The combination of insulation with a stove swop has been tested on a smaller scale during the pilot phase of the current Eskom project.

3.1.2. Advance policy development

Further development of the national policy framework for air quality offsets is required to provide certainty over time to all stakeholders. This includes the development of an air quality accounting standard and associated methodologies. Eskom should actively participate in the development of this framework.

3.1.3. Attend to critical success factors

The following could be considered critical success factors to maximise the chances of a successful AQ offset programme:

- Community interaction
- Interaction with licencing authority
- Legal aspects
- Utilising existing expertise and developing new suppliers

Recommendations

- Quality assurance and quality control
- Risk management
- Programme management
- A well-defined decision making process

3.1.3.1. Community interaction

Community interaction can make or break the large-scale rollout leads and the importance of having thorough interaction with the local community should not be underestimated. Expectation management, consistent messages, local presence and public sessions are examples of very important aspects to be managed professionally. The interaction and contracting of individual households to participate in the project, is of particular importance and great care should be taken to do this properly. In other words, all stakeholders, including Eskom management, should understand and acknowledge that the interaction with households is an indispensable part of the programme.

3.1.3.2. Interaction with licensing authorities

The interactions with the licencing authorities are critical to the success of the air quality offset programme. A formal acceptance by the regulatory authorities of project outcomes as specified in a PDD (project design document) can help to manage risks. Just as the other stakeholders, the regulating authorities also need to grow in their understanding of the complexities and challenges involved in rolling out a community air quality offset programme. This is necessary in order to find an appropriate balance between the urgency to take the programme to scale and the time it takes to do this responsibly.

3.1.3.3. Legal aspects

The AQ offset field is still fairly immature and legal aspects are in process of development. The recommended approach in such a dispensation is to follow best available practice in related fields. During the pre-feasibility phase the legal review recommended that in the absence of specific guidance, air quality offsets projects should be structured similar to greenhouse gas offset projects such as those undertaken under the Clean Development Mechanism of the Kyoto Protocol, of which South Africa is a signatory. The Air Pollution Impacts Protocol as well as the methodologies developed under the feasibility phase of this project as well as the PDD developed for the current phase is an attempt at such an alignment.

3.1.3.4. Utilising expertise and experience and developing new suppliers

It is important for Eskom to follow a two-pronged approach with the appointment of implementation contractors i.e. ensure alignment with BEE and SDL policies together with ensuring appropriate expertise and experience to develop/mentor the implementers.

3.1.3.5. Quality assurance and control

Special attention to both quality assurance and quality control is required. We recommend that appropriate business processes be put in place to manage these aspects.

3.1.3.6. Risk management

Formal risk identification and mitigation/avoidance strategies must be formulated and included in the programme and project plans.

3.1.3.7. Programme management

Well-developed programme management systems together with professional experienced staff on both the Eskom and contractor's sides are essential for success.

3.1.3.8. Decision making

Due to the unknown/new/changing aspects of this AQ offsets programme, Eskom needs to have a well-defined decision making process with fast cycle times from request/issue to decision.

3.1.3.9. Long term maintenance of the intervention

The importance of the effective long term maintenance of interventions can be illustrated as follows:

- With a maintenance rate of 97,5% p.a., 50% of the interventions will remain after 28 years
- With a maintenance rate of 95% p.a., 50% of the interventions will remain after 14 years
- With a maintenance rate of 90% p.a., 50% of the interventions will remain after only 7 years

Long term maintenance depends on mainly two factors: the robustness of the technical intervention and the proper corrective measures in case an intervention is not maintained or used, e.g. by new household formation, wear and tear, LPG that is not available, or other events.

Good progress has been made to optimise the robustness of the technical intervention, as discussed in this report.

To ensure that the proper corrective measures in case an intervention is not maintained or used, a long term strategy for the maintenance of interventions must be developed with the households. This strategy should include elements such as an education programme, a local energy centre and institutional development (see Appendix 3: Institutional development and the long term maintenance of interventions).

The onus is on Eskom to protect their investment in the communities and to determine what the different role players can contribute to the long term maintenance of the interventions. Nova could investigate and experiment with the institutional innovation that is needed to optimise the role of each role player. A local "energy center" in each community may facilitate Eskom and Sasol's continued involvement.[11]

3.1.3.10. A Programme of Activity (PoA) approach

In order to reduce transaction costs in CDM and expand the mechanism's applicability to micro project activities, the CDM Executive Board decided to launch the Programme of Activities modality. One of the main ideas was to streamline the registration and verification of stand-alone CDM projects and by doing so to cut on transaction costs. In a scenario where a particular intervention is duplicated in several different communities, a PoA approach makes sense.

[11] Please refer to Appendix 3: Institutional development and the long term maintenance of interventions for more on institutional development.

3.1.4. Anticipate strategic effects

Community air quality offset projects are particularly complex not only because of the technical complexities involved in measuring and monitoring air quality, but also because of the number of diverse stakeholders involved and the intimate nature of household level interventions. We recommend that Eskom consciously endeavour to anticipate the effects of decisions and communications. To give two examples:

3.1.4.1. Decision by Eskom Executive to implement electricity based solution:

An electrical stove swop has not been properly tested in a pilot phase. Thus, the decision to go for electricity has implications for the timelines for scaling the project, since it can only be responsibly scaled if benefits to end-users have been confirmed and end-users have indicated their satisfaction with the new artefact and usage pattern.

3.1.4.2. Eskom communication to KwaZamokuhle community

Eskom should be particularly careful about creating expectations at KwaZamokuhle (and possibly by precedent elsewhere) regarding non-solid fuel users and larger houses. Community expectations are high following Eskom announcements at the March 2017 LSRG meeting.

3.1.5. Address unanswered questions

There are some unanswered questions that should be addressed in order to optimise the roll-out of the stove swop and full retrofit intervention. The winters of 2017 and 2018 could be used to investigate these remaining questions:

- How does a full retrofit with SPF perform during the winter?
- How effective and sustainable is the SPF ceiling solution?
- How do households who own neither a solid fuel stove nor a LPG stove cope during short and longer power outages?
- How important is the existence of lean-to shacks or mixed structures in a larger sample in terms of potential reversion to coal use?
- How can households and communities be influenced to actively discourage solid fuel use and waste burning?

4. Other recommendations

- Formal only households (households that do not have any extensions) should be targeted first for a full retrofit and stove swop for bested expected results
- The sustainability of the improvements depends on the level of synergy between technical and human factors (financial capacity, skills, confidence) for maintaining the improvements and creating a positive culture of using clean energy as part of improving the general quality of life. Therefore, the interventions should be communicated as a partnership between households (maintenance) and Eskom (facilitating initial transition) as one element of a long-term maintenance strategy
- The concept of a permanent local community energy centre, where community members can purchase maintenance related materials, obtain contacts and knowledge about maintenance should be considered

Chapter 5 Addenda

1. Appendix 1: Appendices and separate documents

The following appendices are included as Addenda to this document:

- Appendix 2: Detailed conclusions and recommendations from pre-paid analysis
- Appendix 3: Institutional development and the long term maintenance of interventions
- Appendix 4: Assessment of Fire Test and use classification of roof envelope section in accordance with SANS 428
- Appendix 5: Details and goodness of fit of generalised linear models used to estimate degree-hours from or within thermal comfort

The following documents/models are not included as Addenda:

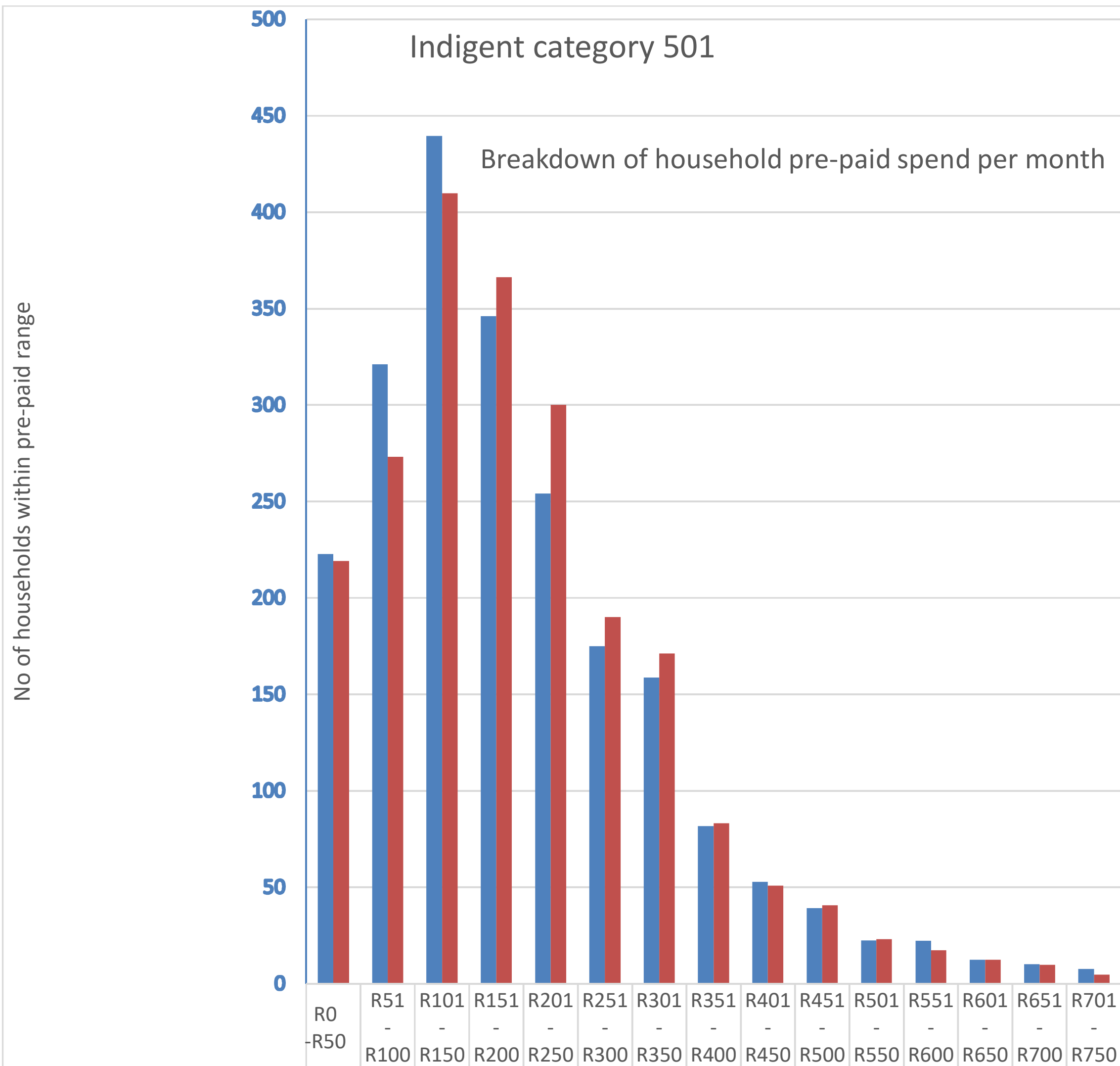
- Project Design Document (PDD which includes intervention spec)
- Process analysis (business processes)
- Cost model
- Combustion Test Results for the Standerton King Stove
- Detailed Energy Survey Questionnaire

2. Appendix 2: Detailed conclusions and recommendations from pre-paid electricity expenditure analysis

2.1. Conclusions

The average pre-paid electricity expenditure per household is similar for summer and winter. On aggregate, electricity savings during the winter due to coal stove usage is probably offset by increased usage of alternative electrical apparatus, including using lights for longer hours.

The majority of municipal energy customers in KwaZamokuhle are classified as indigent. The histogram below depicts their average monthly expenditure for winter and summer, for the period July 2015 to June 2016.



	R0 -R50	R51 - R100	R101 - R150	R151 - R200	R201 - R250	R251 - R300	R301 - R350	R351 - R400	R401 - R450	R451 - R500	R501 - R550	R551 - R600	R601 - R650	R651 - R700	R701 - R750
No households winter/m	223	321	440	346	254	175	159	82	53	39	23	22	13	10	8
No households summer/m	219	273	410	366	300	190	171	83	51	41	23	18	13	10	5

The minority non-indigent category households (40 Amp without FBE) use considerably more electricity than the indigent category. This could be expected as they are prepared to forfeit the FBE and have a need for more simultaneous electrical equipment usage.

Addenda

2.1.1. Sample size

Only when the number of households being monitored becomes large the averages of the pre-paid data become more reliable for homogenous groups. This is due to the many factors that influence pre-paid expenditures e.g.:

- Available cash
- Cost of electricity
- Number of inhabitants
- Holidays, etc.

2.1.2. Comparing seasons

The small difference in average spend for pre-paid between summer and winter leads to the conclusion that the main limiting factor is cash availability and not need for electricity.

2.1.3. Comparing interventions

No fixed conclusion could be made when comparing the different interventions with each other.

2.1.4. Comparing the test group with the reference group

Fortunately, a large number of reference household data sets were obtained and could be analysed.

Relatively small differences in pre-paid values and averages were found.

2.2. Recommendations

2.3. Data gathering

- With regards to pre-paid data gathering it is recommended that in any future similar project the analysts should physically visit the pre-paid departments to ensure proper understanding of the data
- To obtain reliable electricity usage data of an electrical heater a monitor needs to be installed so that date, time of day and duration could be monitored
- To monitor an electric stove the time of day is not so revealing and a kWh meter is sufficient and could be installed either in the DB (distribution board) or at the back of the stove
- The average expense results from the detailed energy surveys were obtained for comparison

2.4. Data analysis

Due to the large data files involved considerable data manipulation is required and an experienced Excel analyst is a pre-requisite to obtain reliable results within an acceptable time frame

- Ongoing checking the results and formulas is essential as Excel can very easily give incorrect results. Consideration could be given to rather use database programming.

2.5. Sensitivity

Future monitoring teams must remember that there is sensitivity regarding electrical usage due to illegal connections. Surveys and inspections must be treated in a sensitive manner.

3. Appendix 3: Institutional development and the long term maintenance of interventions

The importance of the effective long term maintenance of interventions can be illustrated as follows:

- With a maintenance rate of 97,5% p.a., 50% of the interventions will remain after 28 years
- With a maintenance rate of 95% p.a., 50% of the interventions will remain after 14 years
- With a maintenance rate of 90% p.a., 50% of the interventions will remain after only 7 years

Long term maintenance depends on mainly two factors: the robustness of the technical intervention and the proper corrective measures in case an intervention is not maintained or used, e.g. by new household formation, wear and tear, LPG that is not available, or other events.

In this document the term "maintenance" includes all corrective measures to maintain or improve the level of air quality that was obtained after the interventions are implemented.

Maintenance will be needed for different reasons, e.g. one should expect some fall back to coal use for different reasons; the wall cladding is a robust intervention, but after one year (two winters) of use it did exhibit some problems, including:

- Slight damage to outside insulation or plaster – 19%
- Badly damaged outside insulation or plaster – 7%
- Damage to dark paint (north wall) – 19%
- Problem with draft proofing – 2% (1 instance)

These rates could increase over the years.

A lot of work has been done to assure the robustness of the technical interventions, with good effect. A question that must still be sorted out is how long term maintenance should be arranged.

Jim Woodhill (Capacities for Institutional Innovation: A Complexity Perspective, IDS Bulletin Volume 41 Number 3 May 2010) distinguishes between technical innovation and institutional innovation. He refers to a statement of Ministers of developing and donor countries in 2008, that "without robust capacity – strong institutions, systems, and local expertise – developing countries cannot fully own and manage their development processes" (OECD 2008). The same applies to the communities where the interventions are done.

Attention is given to two remarks of Woodhill:

- Institutional innovation includes capacity building and "...a process of strengthening relationships that enable innovation and resilience in communities, organisations and societies..."
- Both technical and institutional innovation are needed, in the correct combination

Addenda

3.1. Role players

Firstly, institutional innovation requires the correct understanding of the roles and mutual relations of the various role players. In this programme, attention can be given to the following role players:

- The households
- Community organisations
- Local and other levels of government
- Local and other levels of businesses
- Eskom and Sasol

If other role players are not involved, that would leave Eskom with the sole responsibility for maintenance. It is therefore important to consider the potential role of each role player.

A few remarks on each role player are made below.

3.1.1. Households

Both technical innovation and institutional innovation require working with households. With technical innovation, new technology must be functionally integrated within the household patterns; with institutional innovation it must be remembered that the household is the first institution that should take ownership of maintaining the interventions in their own homes, in relation to the other role players. This means that the roles that the households can play to maintain the interventions in their own homes must be determined with them.

Key characteristics of households themselves that are required include: taking ownership of the interventions, financial capacity to maintain the interventions, knowledge (e.g. what must be done, where the materials to do so are available); skills (being able to do to maintenance); confidence (a can-do attitude of residents that they can improve their own homes and maintain them or can get someone to do it).

These characteristics mutually influence each other. It is not clear to what extent some could be addressed by giving attention to one of the others, e.g.: would the sense of ownership or self-confidence increase if any of the remaining ones - financial capacity, knowledge or skills – are improved by inputs from outside? Are there certain incentives that would be effective?

These aspects are discussed below.

3.1.1.1. Taking ownership

It is important that residents take ownership of the interventions. Taking ownership includes accepting that you as resident are accountable to maintain the intervention and that taking initiative and action to do so is not someone else’s responsibility. The resident must care about his or her role in the outcome of the whole process, namely cleaner air for all. In KwaZamokuhle it appeared that many households, when approached on their own, tend to feel that they do not have the capacity, financially and otherwise, to do basic maintenance in their homes. The general rates of formal qualifications and a feeling of agency (being able to do something yourself to improve your situation) are low and the rate of unemployment is high.

3.1.1.2. Financial capacity

In the interactions with the residents there were two views on the financial capacity of residents to maintain the interventions: in the individual interactions a large number of residents said that they could not afford to maintain their homes, e.g. to repair a broken window pane. In the group interviews such claims were rejected. The groups insisted that people who say that they do not have money are only making excuses. It was the view of the group that with all the grants that people receive these days, the money is available, they all have money and maintenance isn't expensive

3.1.1.3. Skills

In the group interviews it was claimed that the people who had installed the interventions were there in the community. Some even took part in the group sessions. They have the skills and they are available to maintain interventions. This makes it important to install interventions that can be maintained by skilled people who are locally available.

3.1.1.4. Knowledge

Residents want to know what must be done, and where the materials to do so are available

3.1.1.5. Confidence

A minority of residents expressed confidence that they could improve their homes and maintain them

3.1.1.6. Incentives

An important question is what it is that would motivate residents to maintain the interventions in their homes. From the qualitative research there is only one incentive that has emerged: the dynamic in the group sessions, a can-do attitude. It is in sharp contrast to the powerlessness that was frequently expressed in individual interactions. One may even say that the confidence that came forward in the group sessions was experienced as liberation from powerlessness, and that could set free positive energy

The question is to what extent other role players could make up for the felt lack of capacity of households.

3.1.2. Community organisatons

In group discussions positive energy came forward that may be utilised to empower households. That is a positive development. However, one could conclude that these groups may be too optimistic, e.g.: the groups dismissed the argument that some households cannot afford to buy materials for maintenance. They insisted that people who say that they do not have money are only making excuses. They declared that, with all the grants that people receive these days, the money is available, they all have money and maintenance isn't expensive. In our Quality of Life surveys, however, it seems that many people do not have money to buy enough healthy food

The groups dismissed the argument that some households do not have the necessary skills. They claimed that the people who had installed the interventions were there in the community. They have the skills and they are available to maintain interventions

Regarding the issue of taking ownership of the interventions, the groups argued that people know that they have to maintain their cars, why wouldn't they maintain their homes – while our surveys show that some people at present do not do small repairs, such as replacing broken window panes

The extent to which households can obtain, with the necessary help and support, the necessary capacity needed, must still be evaluated in practice and the capacity building and guidance that will be required will have to be determined.

The present high level of trust in Nova and Eskom provides a window of opportunity for the development of a long term maintenance strategy with households - not only to maintain the interventions but also to maintain the good relationship with the community

3.1.3. Local and other levels of government

Improving the houses of residents has an interface with local and other levels of government – what will their involvement be in the long-term maintenance of the interventions?

3.1.4. Local and other levels of businesses

In the group discussions one aspect that needs attention was emphasised: residents have to know what is needed to maintain each intervention, and where the materials can be found. The image of repairing a car was also used here: if you drive a specific type of car, you must know at which spare part suppliers the spare parts for that car are available. If residents know where the relvant materials can be found, they can get it themselves. Even if this is over-optimistic, the point is correct that local businesses have a role to play to make the correct types of materials available.

Other potential roles of local and other levels of businesses should be considered. The possibility of developing local small enterprises must also be investigated. Studies in ths respect, such as SMMEs and the green economy: muddy waters and murky futures (February 2017, Gordon Institute of Business and Science) is "An investigations into the sustainable practices of small, medium and micro manufacturing enterprises in South Afica's Gauteng Province". There are also interesting courses in small scale entrepreneurial development.

3.1.5. Eskom

The onus is on Eskom to protect their investment in the communities and to determine what the different role players can contribute to the long term maintenance of the interventions. Nova could investigate and experiment with the institutional innovation that is needed to optimise the role of each role player. A local "energy center" in each community may facilitate Eskom's continued involvement.

3.2. Factors influencing long-term maintenance for different interventions

Secondly, we give attention to another remark of Woodhill, namely that both technical and institutional innovation are needed, in the correct combination.

During the technical innovation phase, factors that influence the long-term maintenance of different interventions have been considered. The different interventions are considered below:

3.2.1. Ceiling

The retrofit ceiling design seeks to accommodate and balance both technological and human factors.

Addenda

With regards to maintenance, the most prominent technical factors are:

Long term durability and robustness against challenging conditions. These challenging conditions are mainly poor surfaces to which the installation adheres, and the presence of excessive moisture due to condensation and water leaks. Conventional isolation materials like fiberglass wool, gypsum ceiling boards and normal cornices cannot withstand these conditions. Expanded polystyrene sheeting (EPS) is structurally robust against moisture, but stains badly. EPS also shrinks over time and combined with the poor surfaces it adheres to it does not stay in place as desired.

As insulation material, Spray Polyurethane Foam (SPF) has a closed cell structure which makes it highly water resistant. The SPF may have up to 5% open cells which is an advantage as it allows some moisture to travel through and therefore drying out where moisture gets trapped. The SPF expands on application and fills gaps and holes thereby closing leaks. It is a very good insulator and thus prevents excessive internal condensation. See here for a good study on moisture control by under-roof SPF insulation: https://buildingscience.com/documents/bareports/ba-1312-application-of-spray-foam-insulation-under-plywood-and-osb-roof-sheathing/view. SPF is flexible and can withstand expansion and shrinking of the building envelope. In terms of durability, a general internet search provides many references to the long-term durability of SPF applications. Because cured SPF is an inert polymer it is unlikely to change structure over time and can thus last very long. There are examples of SPF coatings that are 50 years old and still last. Installers often offer warranties in excess of 10 years (http://www.nationalcoatings.com/tech-center/resources/warranty-information). In general, recommendations are that external SPF coatings be recoated every 10-15 years to resist weathering (http://www.sprayfoam.org/files/docs/2014/2D_Recoating_and_Renewal_of_SPF_Roofing_Systems.pdf). Internal SPF coatings will by default last substantially longer as it is not exposed to weather. Although SPF is not generally available for maintenance (yet), it is unlikely that any maintenance of this layer will be required in the short term. There are already SFP compatible foams available in most hardware shops (used for gap filling during construction) which may be used in the unlikely event of damage to the SPF layer.

The gypsum boards, steel brandering and EPS finishing strips are all internal installations. Because the SPF layer seals the roof and prevents condensation, these materials are not exposed to excessive moisture. Also, the finishing strips do not adhere to the walls but only to the gypsum board, thereby circumventing the problem of poor adhesive surfaces. These components are very standard building materials and could be bought at any hardware store if needed.

With regards to maintenance, the most prominent human factors are:

3.2.2. Access to materials for maintenance.
SPF is not readily available, but is expected to last very long. All other components are readily available in all hardware stores.

3.2.3. External cladding/insulation
The external cladding tested by Nova in both feasibility studies (eMbalenhle 2008, Zamdela 2010) and both pilot studies (Kwadela 2013, KwaZamokuhle 2015) in all configurations (EPS and SPF based) has proven to be very robust. The damageable insulation components are protected by a weather- and impact resistant, cementitious, polymer containing, double layer. The layer is flexible, UV proof

and reinforced with fibreglass mesh. The SPF based (expensive ~10%) version is definitely more compact and therefore stronger than the EPS based (less-expensive, -10%) version, but the latter shows no issues w.r.t. major maintenance requirements. If such requirement arose, cementitious, polymer containing plasters and/or foam products are readily available in hardware stores. As many construction workers will be trained and afforded experience in installing these materials it is probable that help to the households will be readily available for maintenance.

3.2.4. LPG equipment

As with all devices which are in regular use components on the LPG devices will fail periodically. Nova stipulates in its advice to program owners that the suppliers of devices be required to open and maintain a local agency which carries spares and have technicians at hand who can do reparations. The coal stoves which households currently use require maintenance too, and it is unlikely that LPG stove, for example, will add to the maintenance burden already on households.

4. Appendix 4: Assessment of Fire Test and use classification of roof envelope section in accordance with SANS 428

The Manager Nova Institute Attention: Mr. H Snyman P. O. Box 38465 Garsfontein East Pretoria 0060	Date: 28 November 2016 Our Reference: 2214/R2

Dear Sirs

RE; Assessment of Fire Test and use classification of roof envelope section in accordance with SANS 428

1 Introduction

1.1 References **SANS 10400-T Fire Protection**
SANS 428 Fire performance classification of thermal insulated building envelope systems
SANS 10177-10 Surface burning characteristics of building materials using the inverted channel tunnel test.

1.2 Credentials of signatory to this assessment

Writer is a registered Professional Engineering Technologist and served as Head of the Fire Testing Department of the South African Bureau of Standards for 15 years and therefore falls into the legal scope of persons who may do such assessments. Full CV is available on request.

1.3 Rational assessment definition from SANS 10400-T

3.68
rational assessment
assessment by a competent person of the adequacy of the performance of a solution in relation to requirements including as necessary, a process of reasoning, calculation and consideration of accepted analytical principles, based on a combination of deductions from available information, research and data, appropriate testing and service experience

2 Request from client

The client requested Topaz Fire Engineering Services CC to assess the applicability of a test conducted on a thermally insulated roof envelope at their premises at 14 Rotterdam Road Apex Benoni. The test to be conducted in accordance with SANS 10177-10. The client also requested Topaz Fire Engineering Services CC to provide a classification of the envelope tested in accordance with SANS 428.
The proposed use of the insulated roof envelope to be tested is for use for single story Category 1 houses and H3 and H4 buildings not higher than 2 storeys.

3 Assessment principle

a) The test specimen was assessed for compliance with the construction configuration provided by the test client.
b) The test specimen was assessed for compliance with the scope of the relevant test standards.
c) The apparatus was assessed for compliance with the requirements of SANS 10177-10.

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d) The test procedures and recording of results were assessed for compliance with the requirements of SANS 10177-10.

4 Applicability of this report

This report relates only to the described sample, test apparatus and test.

Note: All dimensions given in this report are nominal

5 Description of envelope test sample

5.1 Observed test sample composition

- Lip channel spaced parallel at 1,2 meter centres. The height of the channel was in the vertical position.
- Galvanised corrugated iron roofing sheets was fixed across the lip channel and to the top flanges of the lip channel to standard specifications. The total length of the assembly was 7,4 meters and the width without the holding frame 820mm.
- Polyurethane foam was sprayed to the underside of the galvanised corrugated iron to a thickness of 20 mm to 30 mm.
- The exposed surface of the polyurethane foam was covered with a film of an intumescent paint with a nominal dry film thickness of approximately 200µm in thickness.
- Steel brandering was fixed to the bottom flanges of the lip channel by means of 4mm tech screws. The brandering was installed across the lip channel and spaced at 380mm centres.
- Standard SABS approved 6mm gypsum ceiling board was fixed to the steel brandering with steel screws at approximately 220mm centres. At joints the boards were connected with standard steel joining strips ("Bischoff" strips). The first joint was approximately 900mm from the ignition source end of the apparatus.
- The envelope test sample was fixed to a galvanised holding frame constructed to hold the test specimen firmly and to be able to slide the envelope test sample easily into the guides of the test apparatus.
- The test sample is described by the sketches Figures 1 and 2 below.
  Note: The intumescent film painted on top of the Polyurethane foam is not illustrated by these sketches.

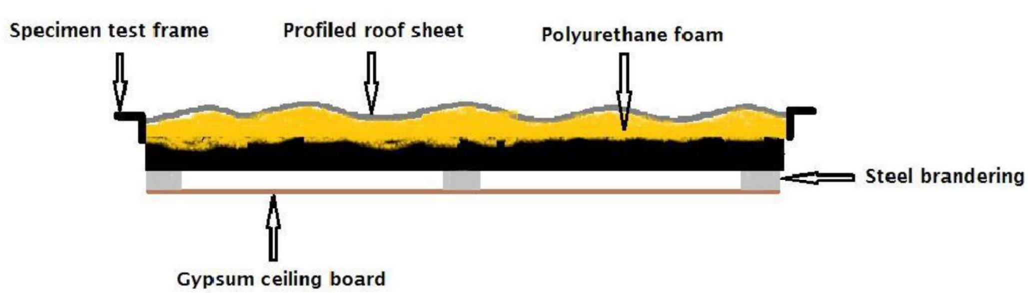

Figure 1. End view of section through building envelope test sample.

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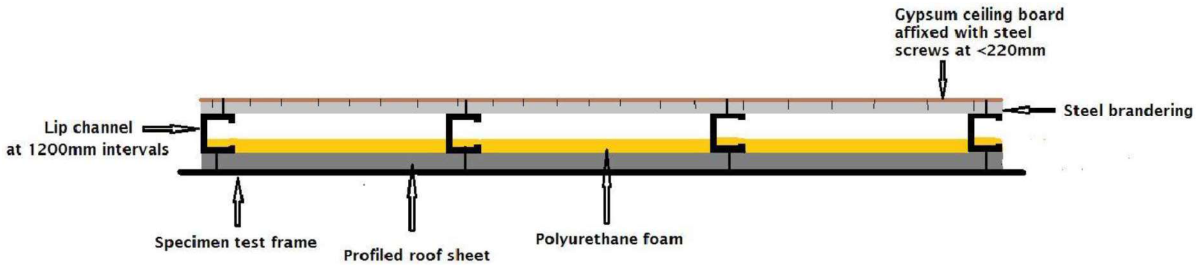

Figure 2. Side view of section through building envelope test sample.

5.2 Specification of the materials provided by client

5.2.1. Galvanised steel holding frame

Manufacturer name: Unknown
Product name: Galvanised Steel angle 25mm x 25mm
Composition or generic identification: Galvanized steel
Thickness: 3mm

5.2.2. Lip channel

Manufacturer name: Unknown
Product name: Lip channel 75mm in height x 50mm wide flanges x 20mm wide lips
Composition or generic identification: Cold-formed lip channel
Thickness: 2mm

5.2.3. Corrugated iron roof sheeting

Manufacturer name: Unknown
Product name: Corrugated iron roof sheeting
Composition or generic identification: S-rib profiled steel sheet, profile depth 20mm and profile pitch 75mm.
Thickness: 0.5mm (Not assessed)

5.2.4. Polyurethane foam

Manufacturer name: Polyurethane and Associated Chemicals South Africa (Not assessed)
Product name: RS-53T (Not assessed)
Composition or generic identification: Two-component, high-density polyurethane foam (Not assessed)
Thickness: 20mm to 30mm

5.2.5. Intumescent paint

Manufacturer name: Self-coat Eco Paint (Not assessed)
Product name: Fireguard Intumescent White (Not assessed)

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Composition or generic identification: Waterborne intumescent coating for fire protection. Provides 30, 60 and 90 minutes fire resistance to structural steel. Tested in accordance with BS 476: Part 21
Application: Single coat by airless spray. (Not assessed)
Dry film thickness: Approximately 200µm.

5.2.6. Brandering

Manufacturer/Supplier: Donn/Saint-Gobain (Not assessed)
Product name: Donn steel brandering 3600mm lengths, 35mm x 17mm; Donn M-strip joining strips. (Not assessed)
Composition and generic identification: Steel brandering

5.2.7. Joining strips

Manufacturer/Supplier: Donn/Saint-Gobain (Not assessed)
Product name: Donn M-strip joining strips. (Not assessed)
Composition and generic identification: Steel 6mm gypsum ceiling board joining strips. (Not assessed)

5.2.8. Gypsum ceiling board

Manufacturer name: Gyproc
Product name: Rhino-board 3600mm x 900mm x 6mm
Composition or generic identification: Gypsum ceiling board SABS approved

6 Description of test apparatus

The test apparatus was nominally constructed in accordance with the specification given by SANS 10177-10. The width between the vertical walls of the test apparatus was adjusted to 830mm to accommodate the envelope test sample.

7 Description of test set-up

The test set-up was nominally as specified by SANS 10177-10:2007 Surface burning characteristics of building materials using the inverted tunnel test as applicable to building envelope test samples. The following details pertain to the test set-up.

7.1 Calibration of test set-up

It was found that the correct height for the ignition source was when the top of the pan containing the hexane is 1350 mm below the ceiling of the test apparatus (1210mm below the test specimen). The calibration curve so determined is given by the curve given under Figure 3.

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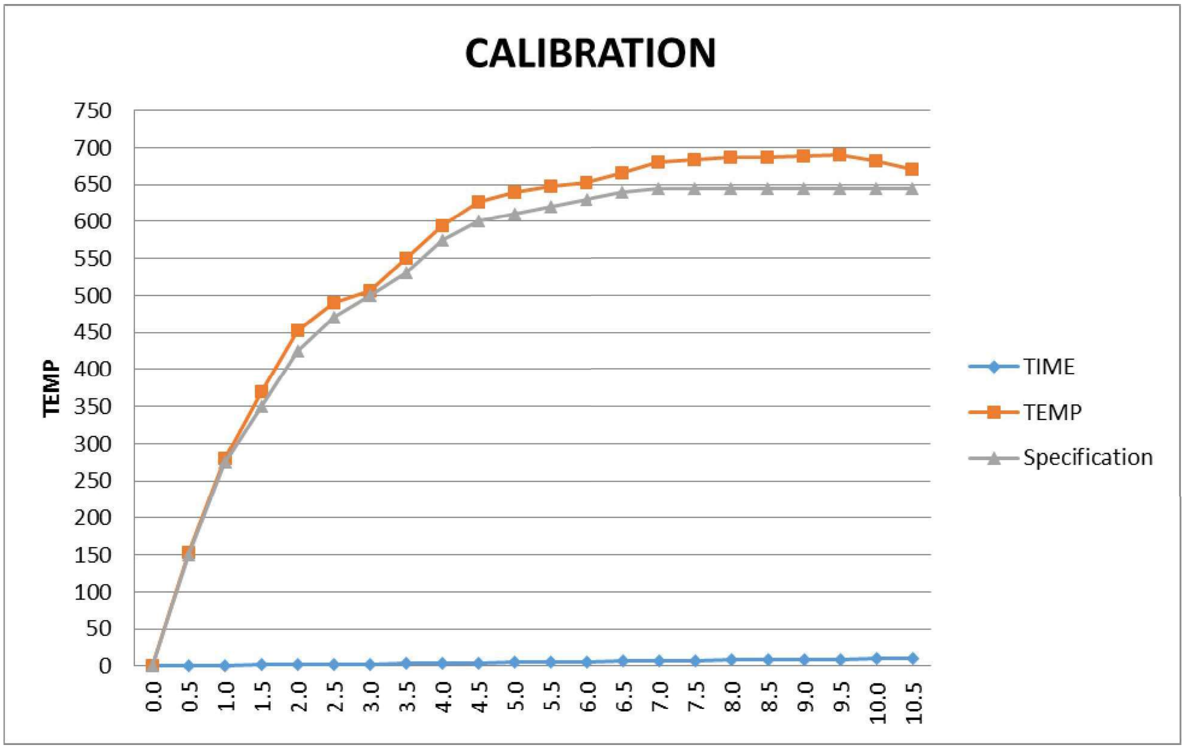

Figure 3. Calibration of flame temperature of test set-up

7.2 The test setup configuration

The test setup was configured to comply with the requirements of SANS 10177-Part 10:2007, the top of the pan containing the fire source was positioned 1210mm below the test specimen and the edge of the pan was positioned 225 mm from the back end of the test apparatus as indicated by figure 1 of SANS 10177-10 :2007 and not 25mm as specified by SANS 10177:10:2007 paragraph 4.1(c).

Two ceilings are relevant in the test set-up described by SANS 10177-10 namely the ceiling of the apparatus before the test specimen is installed and the ceiling in the test set-up after the test specimen was installed. This ceiling in the test apparatus before the installation of the test specimen was used as a reference ceiling for the calibration exercise and the thermocouple to measure the heat output of the fire source was positioned 300mm below this ceiling and centrally above the test fire and designated as thermocouple 1. The position of this thermocouple was not adjusted to measure the temperatures in this area when the actual test was done with the envelope test sample installed.

Additional thermocouples were installed as specified by SANS 10177-10:2007. The thermocouples were installed 2 m, 3 m, 4 m, 5 m, 6 m and 7 m from the back wall and 25 mm below the test specimen and numbered 2, 3, 4, 5, 6 and 7. (Thermocouple 7 did not function and was not considered, in respect of this test it was insignificant that thermocouple 7 did not function as all the thermocouple readings was of no significance as the test specimen did not propagate flame spread.)

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7.3 The test

The test fire was ignited and the time and temperatures at the thermocouples recorded. It was observed whether or not fire spread along the test sample. Ten minutes after the test fire ignited the test observations were terminated.

The materials used in the composition of the test specimen were all assessed for combustibility if tested in accordance with SANS 10177:5:2012.

The environmental temperature during the test: 26 °C.

The test was conducted on 21 November 2016.

The temperature curve during the test is illustrated by figure 4. Series 1 indicates the temperature of the thermocouple above the fire source. One will note that the heat output values given by thermocouple series 1 is generally lower than that of the calibration curve. The area under the curve of the test curve is approximately 70% of the area under the calibration curve. This apparent reduction of heat output is caused by the continuous release of steam by the gypsum board and is not a matter of concern.
The readings of the rest of the thermocouples are of no significance as no flame spread took place.

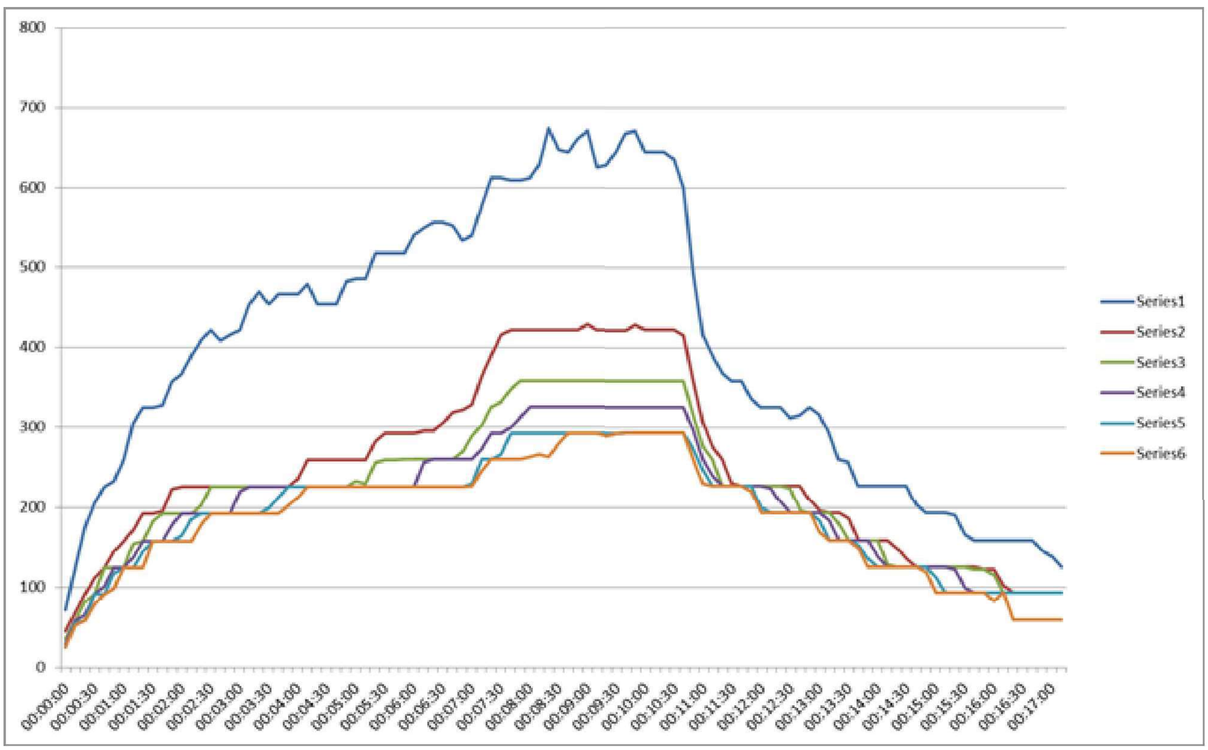

Figure 4. Temperature curve during the test.

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8 Observations during test

The total measured distance, in millimetres, that the test specimen

a) Supported burning (flame spread): No flame spread occurred outside the fire source area.

b) Dripped without flaming droplets: No dripping of any material.

c) Dripped with flaming droplets or burning brand falling to the ground; No burning materials falling to the ground, and

d) dripped with droplets or that burning brand continued burning on the floor: No burning materials falling to the ground.

9 Test results outcome

a) time to ignition; No ignition of the paper covering the gypsum board could be distinguished from the flames of the fire source.

b) Maximum length of flame spread, molten droplets or burning brand, burning molten droplets or burning brands, droplets or brands burning on the ground or damage to material; No flame spread, no molten droplets or burning brand, no burning molten droplets or burning brands, no droplets or brands burning on the ground or damage to material

c) molten droplets during flame propagation; None

d) burning molten droplets of burning brand dropping down during burning. None

e) Record details of any observed phenomena considered relevant; None

f) deviation(s) from the test procedure given in clause 6; None

g) Record details of further tests to be conducted; None. Paragraph 4.3.3 of SANS 428 indicates that the large scale test is not applicable to the intended use of the envelope as it will only be used for Category 1 Buildings and H# and H4 buildings two stories or lower in height.

10 Assessment

10.1 Assessment of construction configuration of test specimen

It was found that the test specimen was constructed according to the construction configuration details provided by the client. Except where indicated otherwise some material details of construction components were also assessed.

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10.2 Assessment of test specimen design with the requirements of applicable SANS Standards

When the SANS 428 classification system is analysed there are such an array of contradictory statements that it is difficult to ascertain whether it is intended to classify materials or composites or building envelopes. The objective of this assessment is to establish whether the materials used is to be classified or whether the classification needs to be done in respect of the composite or envelope.

It was concluded that it is correct to do an assessment of the envelope and not the materials in respect of the specific sample tested, the proof of this is argued below.

10.2.1. Content SANS 428

The title of SANS 428 "Fire performance classification of thermal insulated building envelope systems" leads one to the conclusion that it deals with the classification of building envelope systems.

In its definition of a building envelope system it is clear that the building envelope systems are actually complete walls or roofs.

SANS 428 definitions

Building envelope
External walls and roofs, including insulation material, components and elements used for ceilings and for under-roof and side cladding in buildings

In contradiction to its title SANS 428 stated that in its scope that it SANS 428 intends to cover materials and insulating wall and roof panels.

From the above it is concluded that to test a roof envelope as an entity it is acceptable. Further in SANS 428 reference is made to envelopes that is to be tested in accordance with SANS 10177-10 and it also provide a classification system in respect of the fire properties of such envelopes, which are presumably walls and roofs as an envelope.

Scope SANS 428

This standard covers the classification, usage and application requirements for under-roof and side-cladding insulating materials, liners, insulated wall and roof panels, insulated ceilings and insulated wall and ceiling coating systems for use in buildings of unlimited height when exposed to an ignition source.

10.2.2. Content of SANS 10177-10

In contradiction to SANS 428 SANS 10177-10 clearly stated in its title and scope that it intend to classify materials only. It also explains und clause 3 "Principle" that it deals with material classifications only. But in contradiction to its title its scope and its principle SANS 10177-10 in clauses 4 and 5.1 of SANS 10177-10 it appears that composites and building envelopes are acceptable to be classified.

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10.2.3. Content of SANS 10400:T

Under clause 4.5.3 one conclude again that the classification is about materials only but in the Note to Clause 4.5.3 it appears clearly that combustible thermal insulation should be tested in relation to its use which conclusively approve the testing of the envelope, in this test the roof envelope.

4.5.3 (10400-T) Any insulation, insulating panel or lining used as a thermal insulation system under an external covering as part of a roof or wall assembly (thermal insulated building envelope), tested in accordance with SANS 10177-5 and found to be combustible, shall be acceptable if, when classified in terms of the SANS 428 protocol, its use and application are acceptable.

NOTE The classification methodology contained in SANS 428 is intended to classify thermal insulation materials in accordance with their fire safety performance in respect of thermal insulated building envelopes, and to recommend the usage of the materials in accordance with its classification. SANS 428 further specifies marking and installation requirements in respect of classified products. The classification protocol makes provision for both horizontal and vertical applications, with or without the use of a fixed water-extinguishment (sprinkler) system and designers should take note under which circumstances the thermal insulation materials were classified.

4.12.1.5 (10400-T) When any insulation, roof lining or waterproof membrane not used as a ceiling and used under a roof covering as part of a roof assembly, is tested in accordance with SANS 10177-5 and found to be combustible, such material shall be acceptable should it be classified, marked and installed in accordance with the requirements of SANS 428.

10.2.4. Conclusion

It is concluded that the test specimen was within the scope of the relevant test standard as a building envelope specimen representing a section of a ceiling/roof composite.

10.3 Assessment of combustibility of materials

Of all the materials used only the polyurethane foam and the gypsum ceiling material will classify as combustible when tested in accordance with SANS 10177-5.

10.4 Assessment of Calibrations

Note: As SANS 10177-10 do not provide tolerances to any apparatus construction values it was accepted that values inside a 5% tolerance will be acceptable.

10.4.1. Calibration curve

The heat output of the calibration curve is slightly higher than that of the standard and will not benefit the test samples performance and is therefore assessed to be acceptable.

10.4.2. Fuel used

The identification of the fuel by its container leaves no doubt that the fuel was indeed Hexane especially if the heat output during calibration is considered. The fuel used was therefore assessed to be acceptable. See figure 5.

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Figure 5. The fuel used in the fire pan is identified by the label on the container from which the fuel was dispensed.

10.4.3. Calibration of thermocouples

The calibration certificate provided with the thermocouples indicated its good qualities. Figure 6. It is however nor a system calibration. The system was completed by a reader borrowed from the University of North West. Considering the outcome of the fuel's performance in respect of the calibration curve it is deduced that the thermocouple calibrations were adequately accurate. Furthermore, apart from the calibration curve, thermocouples did not play a significant role in the outcome of this test as no flame spread occur. It is therefore assessed that the quality of the thermal readouts was acceptable for this test assessment.

The thermocouples prescribed in this test are in respect of flame temperature measurement technology not well defined. It is only specified as Type-K thermocouples. To measure flame temperature with a acceptable degree of accuracy one would expect that sheathed thermocouples of the thicker thickness type would have been prescribed. Possibly at least 6 mm. The more accurate means to measure flame temperature is by means of optical pyrometers. The prescription of the thermocouples by the writers of this standard is a clear indication that the writers of this document did not have accurate measurement of flame temperature in mind, thus one can conclude that accurate calibration of the thermocouples prescribed is not a requirement and therefore not a requirement of this standard.

The functional calibration certificate issued by the manufacturer of the thermocouples is displayed by Figure 6.

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Manufacturers of Thermocouples, RTD's and Suppliers of Related Temperature Components

THERMOCOUPLE PRODUCTS (PTY) LTD

PO BOX 15477
HURLYVALE,1609
EDENDALE RD WEST
EASTLEIGH, EDENVALE
GAUTENG, RSA
TEL NO : (011) 452-6617
FAX NO : (011) 452-6243
E-MAIL: tcprod@mweb.co.za

CERTIFICATE OF FUNCTIONAL TEST OF CALIBRATION

DATE: 18th November 2016

Manufacturer:	Thermocouple Products (Pty) Ltd	**Customer:**	Nova Institute
Description:	Thermocouples Type K	**W/o No:**	47685
Part No:	3mm	**Customer Ord#:**	66
Qty:	7 Off	**Ambient:**	25° C

SERIAL NO	VALUE	ACTUAL	SERIAL NO	VALUE	ACTUAL
W/O 47685-1	93 °C	94 °C	W/O 47685-1	649 °C	650 °C
W/O 47685-2	93 °C	94 °C	W/O 47685-2	649 °C	650 °C
W/O 47685-3	93 °C	94 °C	W/O 47685-3	649 °C	650 °C
W/O 47685-4	93 °C	94 °C	W/O 47685-4	649 °C	650 °C
W/O 47685-5	93 °C	94 °C	W/O 47685-5	649 °C	650 °C
W/O 47685-6	93 °C	94 °C	W/O 47685-6	649 °C	650 °C
W/O 47685-7	93 °C	94 °C	W/O 47685-7	649 °C	650 °C
REFERENCE INSTRUMENT			**STANDARDS USED**		
Gometric Model – GMT-250 Serial No. 20898			Dry Bath Thermocouple calibrator – GMT-250		

Note:

1. The measuring standard used for the purpose of this certification was calibrated by or is traceable to a National / International Standards laboratory.
2. The values in this certificate are correct at the time of calibration/certification. Subsequently the accuracy will depend on such factors as operating temperature, the care exercised in handling, frequency of use and its use under condition other than specified by the Manufacturer and/or condition of calibration/certification. Recertification should be performed after a period which has been chosen to ensure that the equipment's accuracy remains within the limits required.
3. Testing has been carried out under an ambient temperature of 25 ° C.
4. In the event of a mistake being made by THERMOCOUPLE PRODUCTS (PTY) LTD in calibration and/or certification, any legal liability arising therefrom shall be limited to the cost of recalibration and/or certification, but the applicant indemnifies THERMOCOUPLE PRODUCTS (PTY) LTD against any consequential or other loss.

Test Person: ______________ **Checked by:** ______________
R.H. RABEY

Figure 6. Certificate illustrating the functional calibrations of the thermocouples used.

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10.4.4. Stop Watch

Verification of the stop watch against the world clock is acceptable for the purpose of this test that needs a timing device to determine the 10 minute cut-off time. The fact that the fire source died out soon after the cut-off time is another indicators of the acceptability of the timing device used. The timing device is assessed to be acceptable.

10.4.5. Measuring tape
Considering the relative robustness of fire testing apparatus and the general accuracy of commercial measuring tapes it was assessed that the measuring tape used was accurate enough to measure the test apparatus to assess compliance with the intent of SANS 10177-10. As a control three other measuring tapes of different makes were compared with the measuring tape used, all three other measuring tapes produced essentially similar measurements up to 2,5 meters. It was therefore assessed that the measuring tape used to measure the test apparatus was of adequate accuracy.

10.4.6. Configuration of test apparatus

SANS 10177-10 specifies that a steel frame must be constructed and the inside clad with boards. The test apparatus used for the test was constructed by cladding the steel frame on the outside. The test method allows the test frame width to be adjusted by a 30% plus variation. Such an adjustment of width, and considering the heat absorption of such an air gap, and compare it with the potential heat absorption ability of an inside light steel frame it is doubtful that the steel inside the test channel will provide significant cooling effects. It was assessed by applying engineering judgement that the steel frame on the inside of the board cover did not significantly influence the test result and was acceptable for this test.

10.5 Test set-up and test

Our assessment was that the test set-up and test complies with the intent of SANS 10177-10. SANS 10177-10 do not specify any tolerances on measurements and also no calibration requirements.

10.6 Test outcome and classification in accordance with SANS 428

It was assessed that with reference to SANS 428:2012 and the outcome of the test the following criteria were met.
Some combustible materials are present: B classification
No flame spread occurs: B1 classification
The use classification is in respect of H3 and H4 buildings: Use classification is 1 therefore suitable to be used in respect of H3 and H4 buildings which require a use classification of 3 or better. Buildings to be not more than two storeys in height.
(SANS 428 stipulates minimum usage requirements in table A.4 by means of numbers but do not explain how the test number is allocated based on the test. In the context of SANS 428 it was deduced that the flame spread number is the test result to be used to assess compliance with the usage number and this principle was applied.)

Horizontal test assessment only: H classification
Assessment not conducted with a sprinkler system: USP classification

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The complete SANS 428 Classification of the described roof envelope is therefore: B/B1/1/H/USP and the roof envelope is viewed suitable by the assessor to be used in Category 1 buildings and in H3 and H4 buildings based on the SANS 428 test and classification regime provided that the H3and H4 buildings are not more than two stories in height.

We trust that this information will meet your requirements.

Yours faithfully,

………………………
J J du Plessis
Pr Tech Eng ECSA number 9170137

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5. Appendix 5: Details and goodness of fit of generalised linear models used to estimate degree-hours from or within thermal comfort

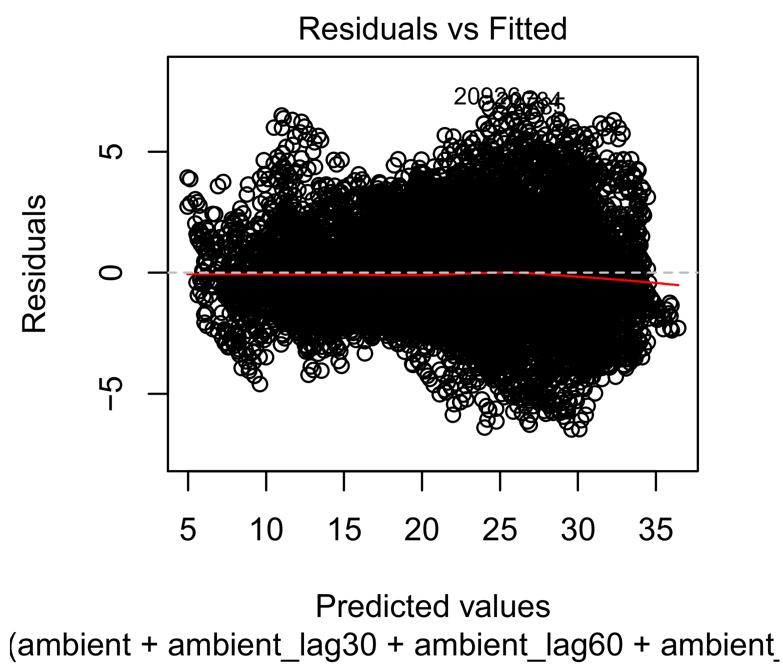
Detail and goodness of fit of generalised linear models used to predict indoor temperature for thermal comfort analysis in terms of degree-hours within or outside of the thermal comfort range

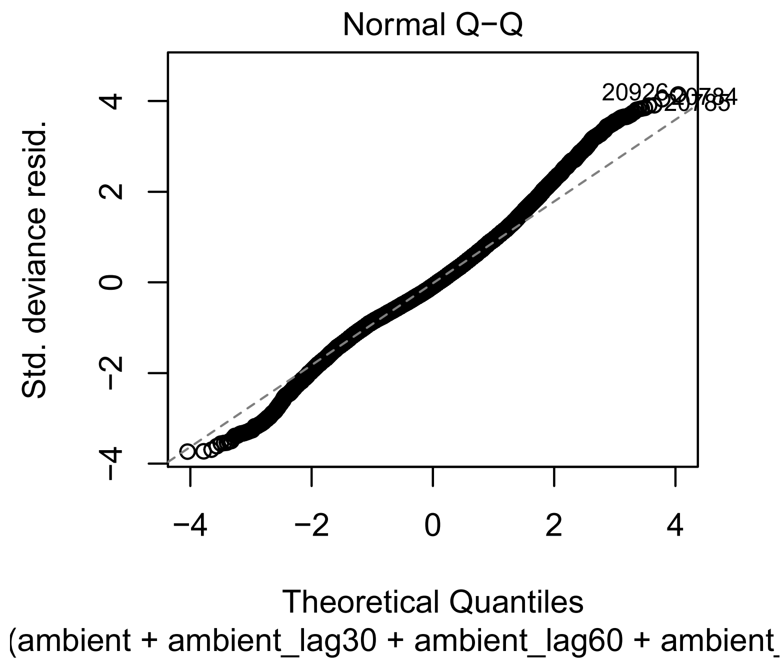
Control group

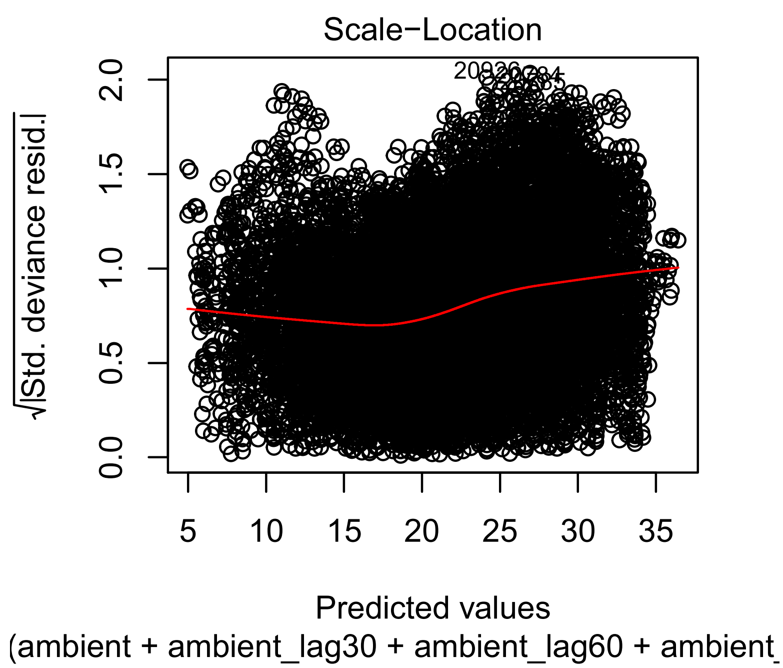
Formula

temp ~ (ambient + ambient_lag30 + ambient_lag60 + ambient_lag120 + ambient_lag360 + ambient_lag720) * (hod * dow + n_hrs_from_sunrise * n_daylighthrs) + hod:(n_hrs_from_sunrise + n_daylighthrs) + (dow:dom):(n_hrs_from_sunrise * n_daylighthrs) + (dow:dom):(ambient_lag1440 + ambient_lag2880) + hod

Goodness of fit




Normal Q−Q
Std. deviance resid.
4
2
0
−2
−4
−4
−2
0
2
4
Theoretical Quantiles
(ambient + ambient_lag30 + ambient_lag60 + ambient_


Scale−Location
√|Std. deviance resid.|
2.0
1.5
1.0
0.5
0.0
5
10
15
20
25
30
35
Predicted values
(ambient + ambient_lag30 + ambient_lag60 + ambient_

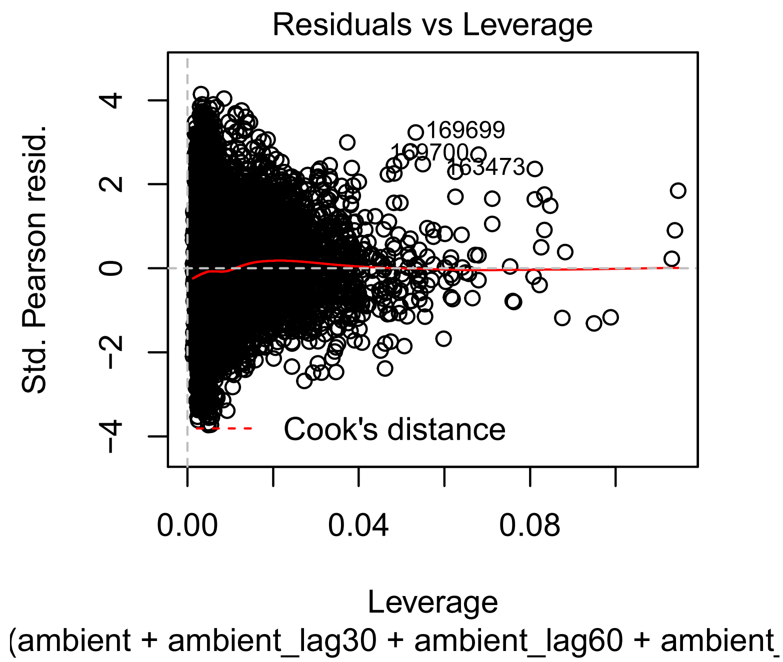


Table 1: Most significant terms (first 50) for 'control_none' GLM

term	t value	Pr(>|t|)
n_daylighthrs	-24.212534	0.0000000
(Intercept)	22.330721	0.0000000
hod:n_hrs_from_sunrise	-19.118965	0.0000000
hod:n_daylighthrs	15.087709	0.0000000
hod	-13.750192	0.0000000
dowFri:dom:ambient_lag1440	13.621223	0.0000000
ambient_lag720:n_hrs_from_sunrise	12.773795	0.0000000
n_hrs_from_sunrise:n_daylighthrs	-10.612992	0.0000000
dowSat:dom:ambient_lag2880	-9.963775	0.0000000
dowFri:dom:ambient_lag2880	-9.264971	0.0000000
dowSat:dom:ambient_lag1440	9.178067	0.0000000
n_hrs_from_sunrise	9.084136	0.0000000
ambient_lag720:n_hrs_from_sunrise:n_daylighthrs	-8.958911	0.0000000
dowMon:dom:ambient_lag2880	8.665578	0.0000000
ambient_lag720:hod	-8.229209	0.0000000
dowFri:n_daylighthrs:dom	-7.396688	0.0000000
ambient:n_hrs_from_sunrise:n_daylighthrs	6.482717	0.0000000
hod:dow.C	-6.157247	0.0000000
dowWed:n_hrs_from_sunrise:dom	-5.794142	0.0000000
dowWed:n_hrs_from_sunrise:n_daylighthrs:dom	5.714395	0.0000000
ambient_lag120:n_hrs_from_sunrise:n_daylighthrs	-5.622373	0.0000000
hod:dow^5	-5.558845	0.0000000
dowSun:n_hrs_from_sunrise:dom	-5.539342	0.0000000
hod:dow^6	-5.289534	0.0000001
ambient_lag360:dow^6	-5.235367	0.0000002
ambient_lag720:hod:dow^4	-5.167414	0.0000002

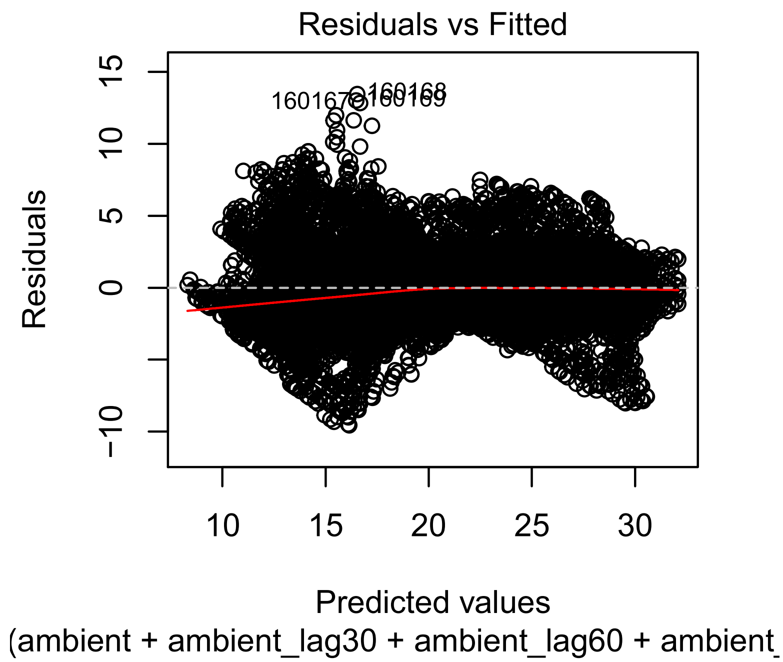
term	t value	Pr(>|t|)
ambient_lag720:hod:dow^5	5.167023	0.0000002
ambient_lag720:dow^5	-5.143576	0.0000003
dowSun:n_hrs_from_sunrise:n_daylighthrs:dom	5.077881	0.0000004
dowMon:dom:ambient_lag1440	-4.959910	0.0000007
ambient_lag360:hod:dow^6	4.742215	0.0000021
ambient_lag360:dow^4	-4.306279	0.0000167
dowSat:n_hrs_from_sunrise:n_daylighthrs:dom	4.194443	0.0000275
dow^4	-4.117726	0.0000384
ambient_lag360:n_daylighthrs	3.907780	0.0000935
dow^6	3.816454	0.0001358
dowSat:n_hrs_from_sunrise:dom	-3.746501	0.0001799
hod:dow.L	-3.647755	0.0002653
ambient_lag120:n_daylighthrs	3.589696	0.0003319
ambient_lag120:n_hrs_from_sunrise	3.575026	0.0003511
ambient_lag720:dow^4	3.373946	0.0007425
ambient:n_daylighthrs	-3.369041	0.0007558
hod:dow^4	3.331145	0.0008666
dowMon:n_daylighthrs:dom	-3.311043	0.0009312
ambient	3.275726	0.0010558
ambient_lag360:hod:dow.L	3.034894	0.0024095
dow^5	3.023468	0.0025023
ambient_lag360:hod:dow^5	3.023454	0.0025024
ambient_lag120:dow.L	2.940489	0.0032809
dowSun:dom:ambient_lag1440	2.860906	0.0042290

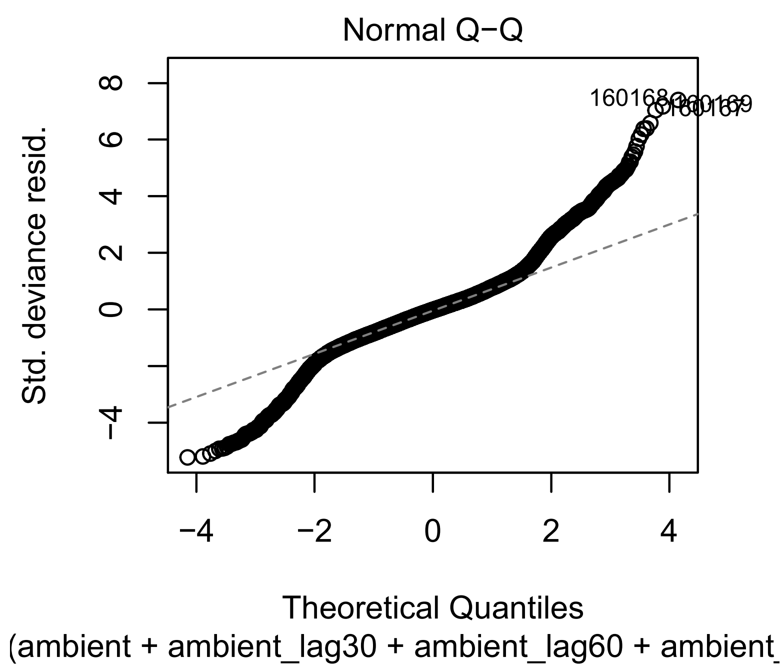
Coal-basic

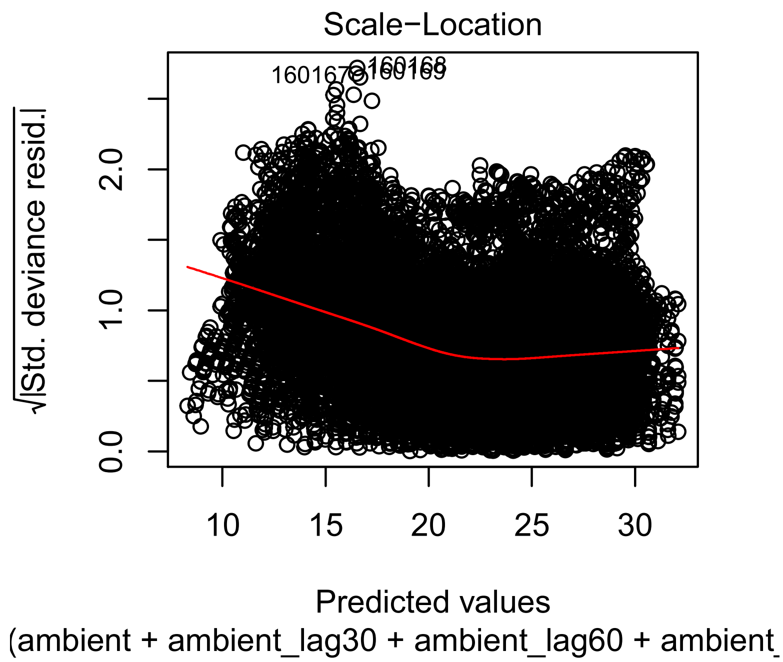
Formula

temp ~ (ambient + ambient_lag30 + ambient_lag60 + ambient_lag120 + ambient_lag360 + ambient_lag720) * (hod * dow + n_hrs_from_sunrise * n_daylighthrs) + hod:(n_hrs_from_sunrise + n_daylighthrs) + (dow:dom):(n_hrs_from_sunrise * n_daylighthrs) + (dow:dom):(ambient_lag1440 + ambient_lag2880) + hod

Goodness of fit







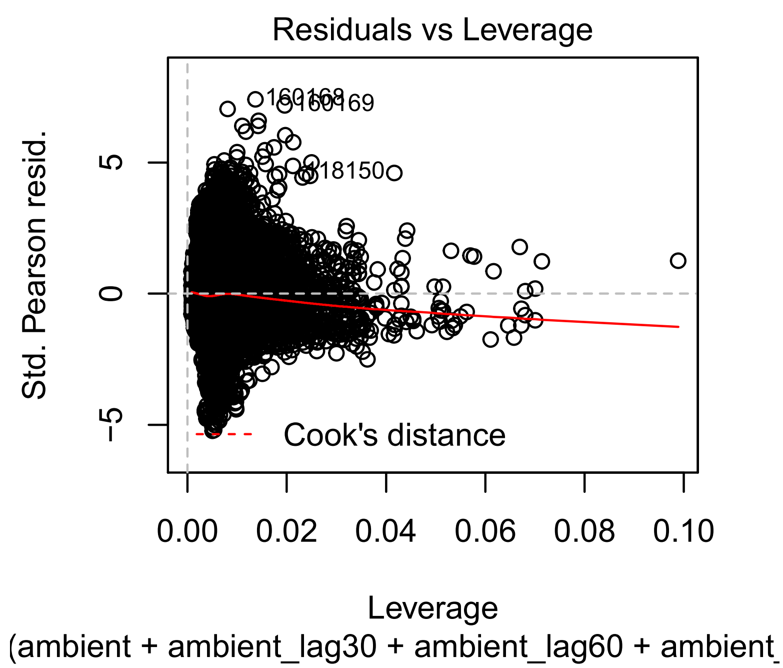


Table 2: Most significant terms (first 50) for 'coal_basic' GLM

term	t value	Pr(>|t|)
dowWed:n_daylighthrs:dom	-24.145715	0.0000000

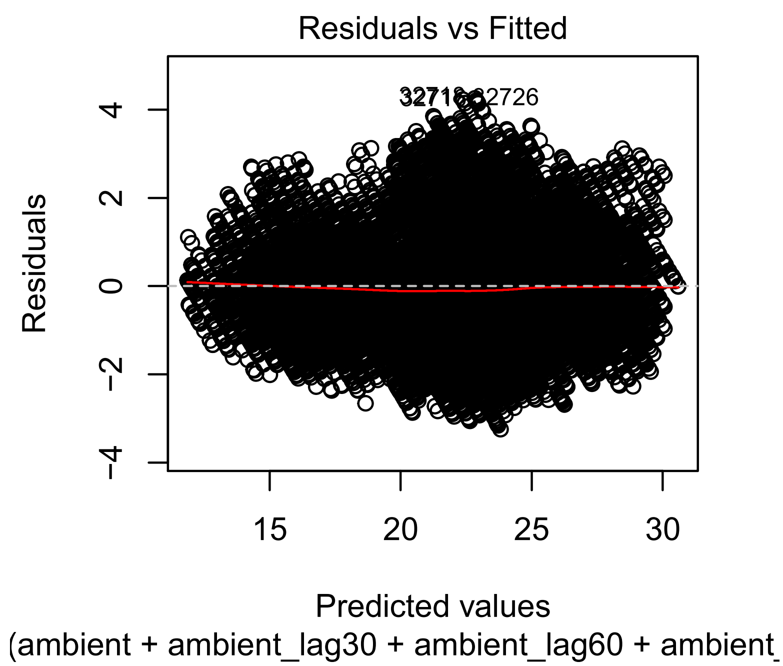
term	t value	Pr(>|t|)
dowThurs:n_daylighthrs:dom	-20.900030	0.0000000
dowFri:n_daylighthrs:dom	-20.825324	0.0000000
(Intercept)	18.524729	0.0000000
n_daylighthrs	-18.351004	0.0000000
dowTues:n_daylighthrs:dom	-17.873396	0.0000000
dowSat:n_hrs_from_sunrise:dom	14.941827	0.0000000
dowSun:n_hrs_from_sunrise:dom	14.842652	0.0000000
dowSun:n_hrs_from_sunrise:n_daylighthrs:dom	-14.629769	0.0000000
dowSat:n_hrs_from_sunrise:n_daylighthrs:dom	-14.578623	0.0000000
hod:n_daylighthrs	14.514990	0.0000000
dowMon:n_daylighthrs:dom	-14.179417	0.0000000
n_hrs_from_sunrise:n_daylighthrs	-14.036736	0.0000000
hod	-13.089499	0.0000000
n_hrs_from_sunrise	12.948132	0.0000000
ambient_lag720:hod	-11.308742	0.0000000
dowThurs:dom:ambient_lag1440	10.298547	0.0000000
dowFri:dom:ambient_lag1440	10.278162	0.0000000
dowSat:n_daylighthrs:dom	-10.000332	0.0000000
dowFri:n_hrs_from_sunrise:n_daylighthrs:dom	-9.721433	0.0000000
ambient_lag720:n_hrs_from_sunrise	9.317003	0.0000000
dowFri:n_hrs_from_sunrise:dom	9.124940	0.0000000
ambient_lag720:n_daylighthrs	7.994590	0.0000000
dowWed:dom:ambient_lag1440	7.671997	0.0000000
dow.C	-7.060853	0.0000000
dow^4	-6.955299	0.0000000
dowSun:dom:ambient_lag2880	-6.922159	0.0000000
dowTues:dom:ambient_lag2880	6.656498	0.0000000
dow.Q	-6.596690	0.0000000
dowSat:dom:ambient_lag1440	6.078643	0.0000000
ambient_lag360:hod:dow^6	5.999604	0.0000000
dowMon:dom:ambient_lag2880	5.310905	0.0000001
ambient_lag360:dow.L	5.268696	0.0000001
dow^5	5.211862	0.0000002
ambient_lag360:dow^6	-5.152249	0.0000003
hod:dow^6	-5.094175	0.0000004
dowWed:dom:ambient_lag2880	5.044795	0.0000005
dow.L	5.030995	0.0000005
ambient_lag360:dow.Q	5.008576	0.0000006
dowThurs:n_hrs_from_sunrise:dom	4.937338	0.0000008
dowThurs:n_hrs_from_sunrise:n_daylighthrs:dom	-4.864318	0.0000012
ambient_lag360:n_hrs_from_sunrise:n_daylighthrs	4.788616	0.0000017
ambient_lag360:hod:dow.Q	-4.712221	0.0000025
ambient_lag360:dow.C	4.349965	0.0000137
ambient_lag360:hod:dow.L	-4.257180	0.0000208
dowMon:n_hrs_from_sunrise:n_daylighthrs:dom	-4.157274	0.0000323
ambient_lag720:dow^5	-4.020767	0.0000582
hod:dow^5	-3.742380	0.0001826
dowSun:dom:ambient_lag1440	3.542048	0.0003976
dow^6	3.386879	0.0007078

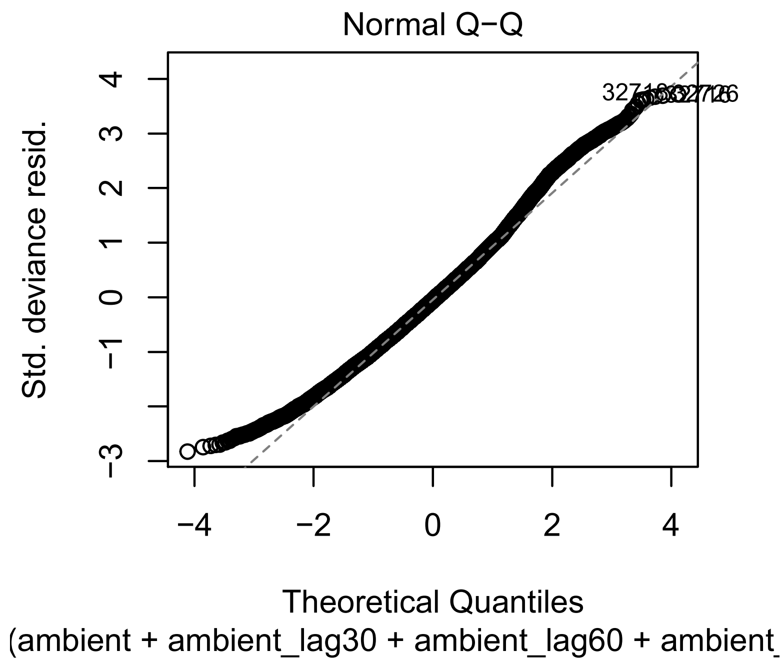
Coal-full

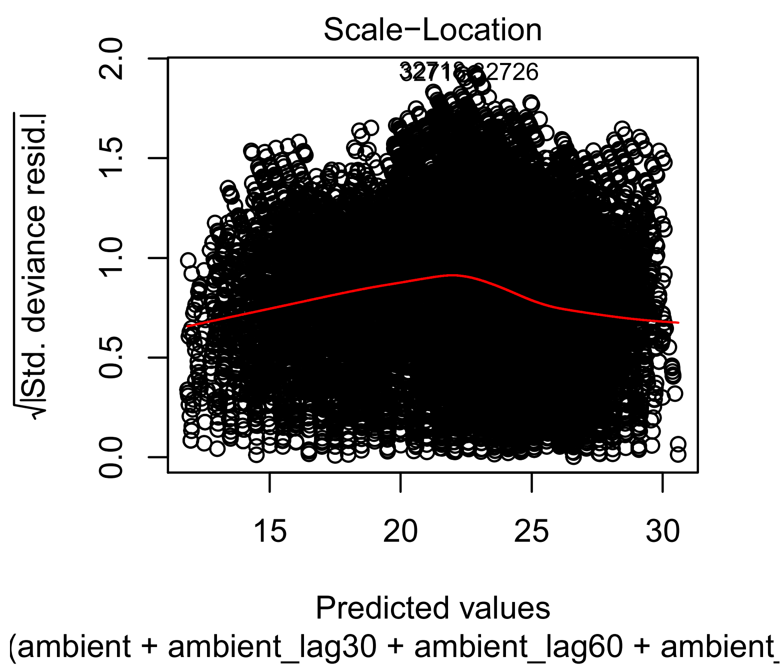
Formula

temp ~ (ambient + ambient_lag30 + ambient_lag60 + ambient_lag120 + ambient_lag360 + ambient_lag720) * (hod * dow + n_hrs_from_sunrise * n_daylighthrs) + hod:(n_hrs_from_sunrise + n_daylighthrs) + (dow:dom):(n_hrs_from_sunrise * n_daylighthrs) + (dow:dom):(ambient_lag1440 + ambient_lag2880) + hod

Goodness of fit




Normal Q−Q
Std. deviance resid.
Theoretical Quantiles
(ambient + ambient_lag30 + ambient_lag60 + ambient_


Scale−Location
√|Std. deviance resid.|
Predicted values
(ambient + ambient_lag30 + ambient_lag60 + ambient_

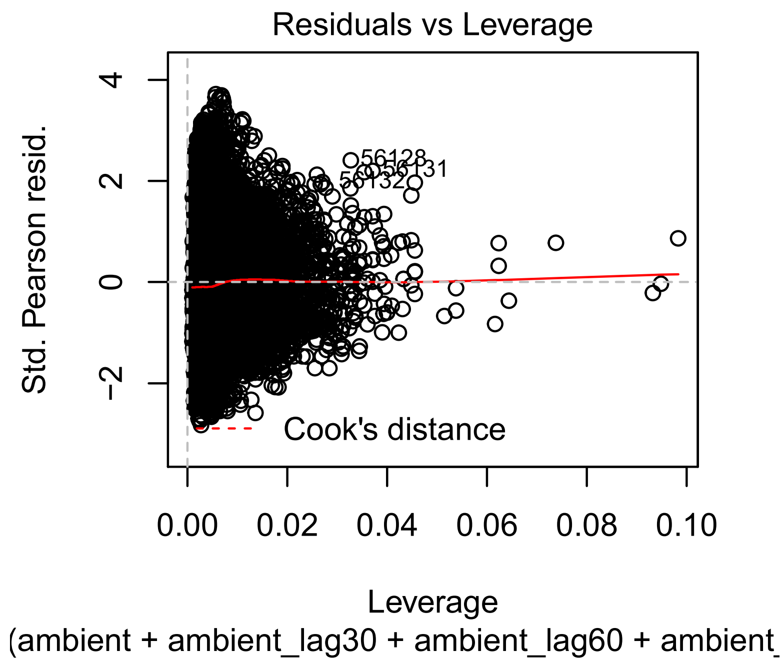


Table 3: Most significant terms (first 50) for 'coal_full' GLM

term	t value	Pr(>|t|)
dowThurs:n_daylighthrs:dom	-15.554968	0.0000000
dowFri:n_daylighthrs:dom	-12.818894	0.0000000
dowMon:n_daylighthrs:dom	-12.729091	0.0000000
dowMon:dom:ambient_lag2880	10.433878	0.0000000
dowSat:dom:ambient_lag1440	10.184657	0.0000000
dowFri:dom:ambient_lag1440	10.007139	0.0000000
ambient_lag120:n_hrs_from_sunrise:n_daylighthrs	-9.144161	0.0000000
dowSat:n_daylighthrs:dom	-8.136394	0.0000000
ambient_lag360:dow.Q	-7.893332	0.0000000
ambient_lag360:hod:dow.Q	7.301816	0.0000000
dowSun:dom:ambient_lag1440	7.008137	0.0000000
ambient_lag720:n_daylighthrs	-6.844764	0.0000000
ambient_lag720:dow.Q	6.812245	0.0000000
ambient_lag720	6.696649	0.0000000
dowSat:dom:ambient_lag2880	-6.494408	0.0000000
dowThurs:n_hrs_from_sunrise:n_daylighthrs:dom	-5.859309	0.0000000
dowTues:dom:ambient_lag2880	-5.738880	0.0000000
dowFri:dom:ambient_lag2880	-5.537791	0.0000000
ambient_lag720:hod:dow.Q	-5.526641	0.0000000
ambient_lag120:n_hrs_from_sunrise	5.496646	0.0000000
dowThurs:n_hrs_from_sunrise:dom	5.480514	0.0000000
dowThurs:dom:ambient_lag2880	5.334305	0.0000001
dowFri:n_hrs_from_sunrise:n_daylighthrs:dom	-5.294124	0.0000001
dowFri:n_hrs_from_sunrise:dom	5.093862	0.0000004
dow^6	5.034330	0.0000005
ambient_lag360:n_hrs_from_sunrise:n_daylighthrs	4.997670	0.0000006

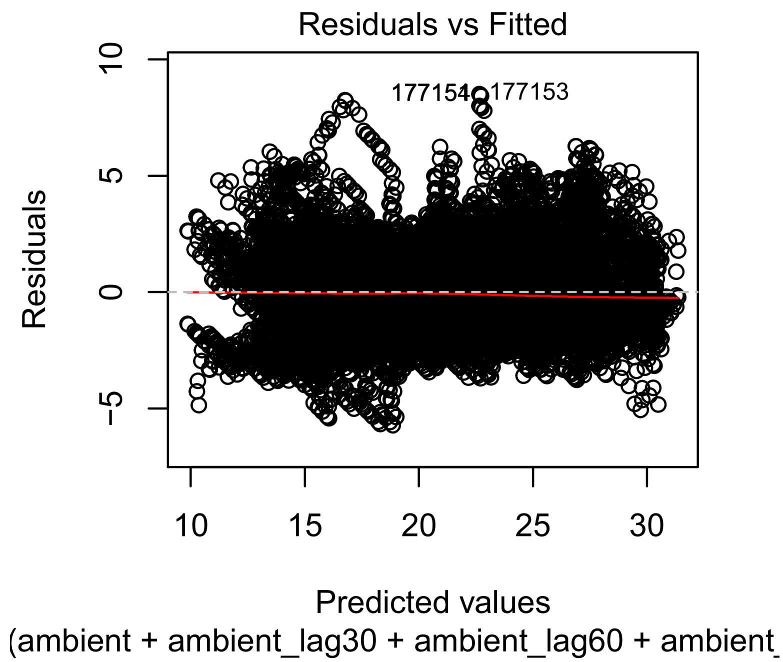
term	t value	Pr(>|t|)
ambient__lag360:dow^6	-4.965419	0.0000007
ambient:n__daylighthrs	-4.950382	0.0000007
ambient:n__hrs__from__sunrise:n__daylighthrs	4.922944	0.0000009
hod:n__daylighthrs	4.914758	0.0000009
hod	-4.893896	0.0000010
ambient__lag360:hod:dow^6	4.614566	0.0000040
ambient	4.306407	0.0000167
dowSun:n__daylighthrs:dom	-4.234373	0.0000230
dowWed:n__daylighthrs:dom	-4.124537	0.0000373
ambient__lag720:hod:dow^6	-4.111837	0.0000394
ambient__lag360:dow.L	-4.000858	0.0000633
ambient__lag720:n__hrs__from__sunrise:n__daylighthrs	-3.889404	0.0001007
hod:dow^6	-3.815910	0.0001360
ambient__lag360:hod:dow.C	3.454913	0.0005514
ambient__lag720:hod:dow^5	3.283499	0.0010266
dowWed:dom:ambient__lag2880	3.275191	0.0010573
hod:dow.C	-3.216497	0.0012993
ambient:hod:dow^5	-3.215164	0.0013053
dowSun:n__hrs__from__sunrise:dom	-3.152100	0.0016229
ambient__lag360:dow.C	-3.106873	0.0018928
ambient__lag360:n__hrs__from__sunrise	-3.076586	0.0020961
ambient__lag720:n__hrs__from__sunrise	3.014436	0.0025771
dowSun:dom:ambient__lag2880	-2.938627	0.0032996
dowTues:dom:ambient__lag1440	2.925648	0.0034404

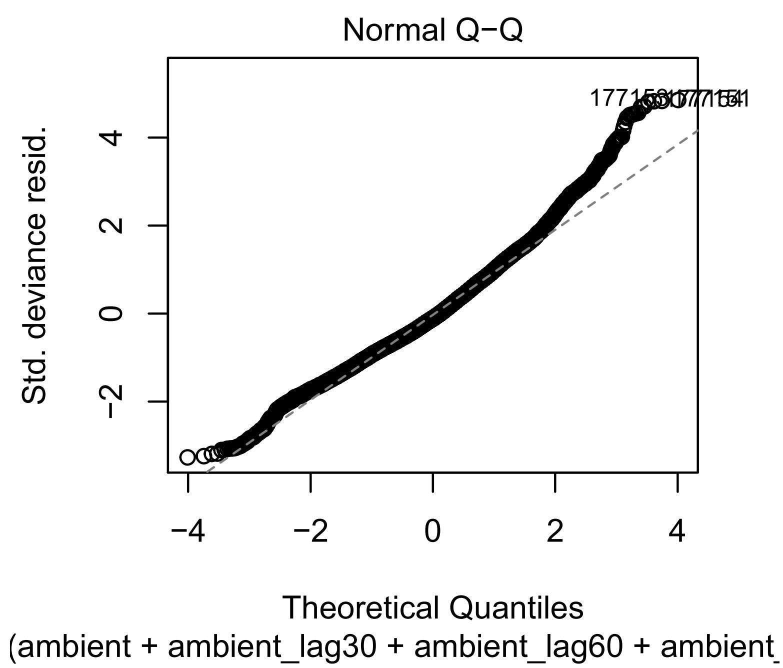
Elec-basic

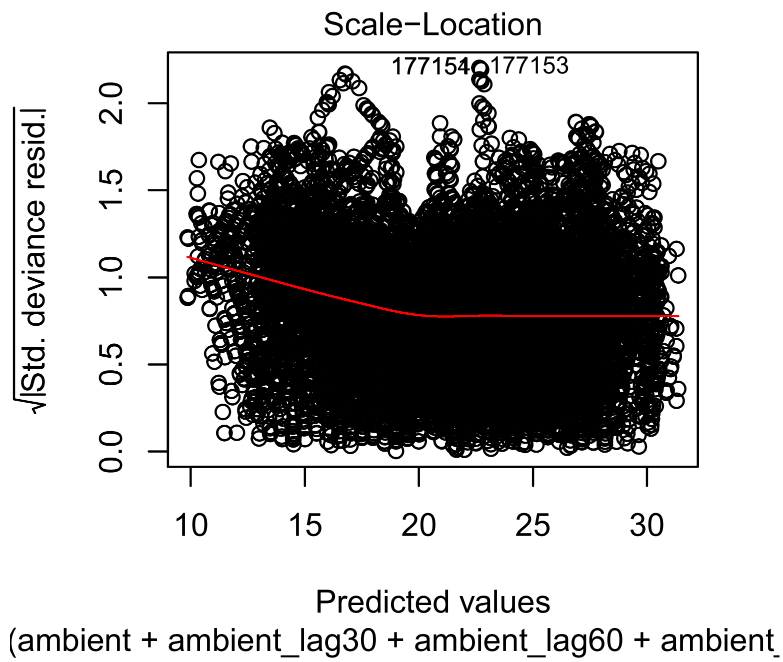
Formula

temp ~ (ambient + ambient__lag30 + ambient__lag60 + ambient__lag120 + ambient__lag360 + ambient__lag720) * (hod * dow + n__hrs__from__sunrise * n__daylighthrs) + hod:(n__hrs__from__sunrise + n__daylighthrs) + (dow:dom):(n__hrs__from__sunrise * n__daylighthrs) + (dow:dom):(ambient__lag1440 + ambient__lag2880) + hod

Goodness of fit







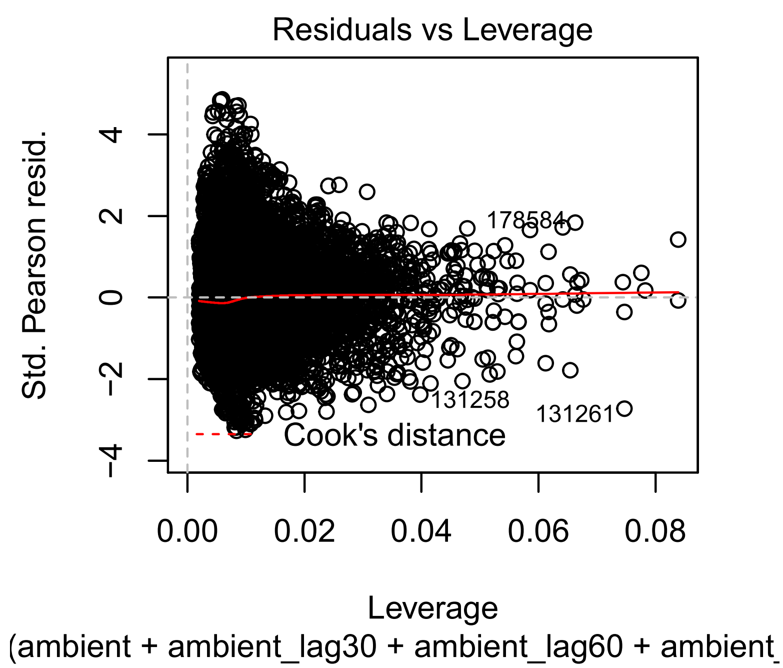


Table 4: Most significant terms (first 50) for 'elec_basic' GLM

term	t value	Pr(>|t|)
dowFri:n_daylighthrs:dom	-19.414708	0.0000000

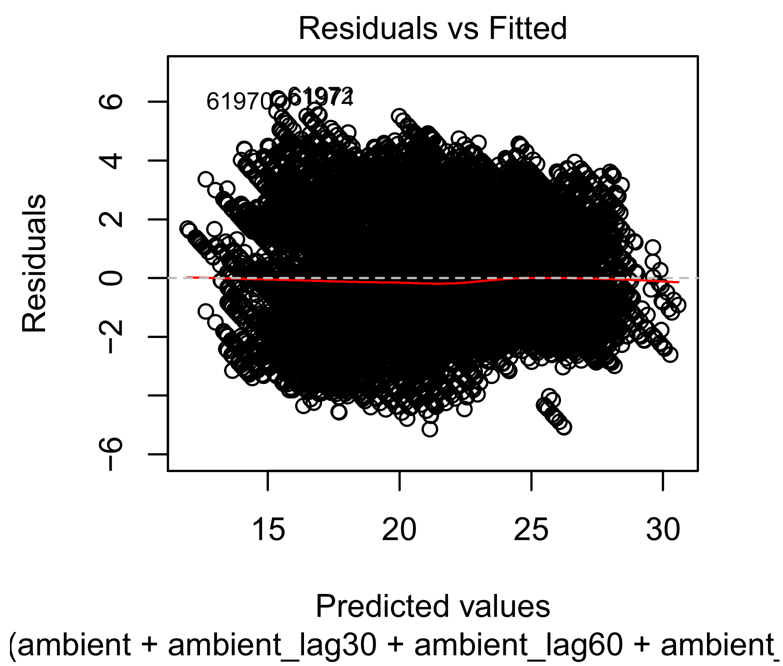
term	t value	Pr(>|t|)
dowThurs:n__daylighthrs:dom	-16.773726	0.0000000
dowSat:n__daylighthrs:dom	-13.432289	0.0000000
dowMon:n__daylighthrs:dom	-13.363948	0.0000000
dowMon:dom:ambient__lag2880	11.813819	0.0000000
dow.L	11.391630	0.0000000
dowFri:dom:ambient__lag1440	9.417377	0.0000000
hod:dow.L	-8.644690	0.0000000
hod:n__hrs__from__sunrise	8.448128	0.0000000
dowSun:dom:ambient__lag1440	7.473667	0.0000000
dowWed:n__daylighthrs:dom	-7.343266	0.0000000
dowThurs:dom:ambient__lag1440	7.278239	0.0000000
dow^4	-6.907221	0.0000000
hod:dow^6	-6.403784	0.0000000
dowSat:dom:ambient__lag1440	6.383690	0.0000000
ambient__lag720:dow.Q	5.970613	0.0000000
dowWed:dom:ambient__lag1440	5.814945	0.0000000
dow^6	5.310701	0.0000001
dowSat:n__hrs__from__sunrise:dom	5.264751	0.0000001
ambient__lag360:n__daylighthrs	5.113675	0.0000003
hod:dow.C	-4.573269	0.0000048
ambient__lag360:dow^6	-4.447007	0.0000088
(Intercept)	4.423032	0.0000098
dowSat:n__hrs__from__sunrise:n__daylighthrs:dom	-4.208119	0.0000259
dowFri:n__hrs__from__sunrise:n__daylighthrs:dom	-3.981942	0.0000687
ambient__lag360:dow^5	3.910881	0.0000923
ambient__lag360:hod:dow^5	-3.812447	0.0001381
ambient__lag720:hod:dow.Q	-3.682944	0.0002313
dowTues:dom:ambient__lag1440	-3.676682	0.0002370
dow.Q	-3.648060	0.0002651
ambient__lag720:n__hrs__from__sunrise:n__daylighthrs	3.522479	0.0004287
dowFri:n__hrs__from__sunrise:dom	3.520540	0.0004318
ambient__lag360:hod:dow^6	3.405290	0.0006625
dowThurs:dom:ambient__lag2880	-3.155485	0.0016052
ambient__lag360:hod:dow.C	3.068229	0.0021569
ambient__lag720:dow.C	3.055039	0.0022540
dowSun:n__daylighthrs:dom	-3.044222	0.0023366
ambient__lag720:dow^4	2.976577	0.0029191
hod:dow^5	2.943973	0.0032449
dowSun:dom:ambient__lag2880	-2.942587	0.0032594
ambient__lag360:dow.L	-2.934451	0.0033461
dowTues:n__hrs__from__sunrise:dom	2.896033	0.0037842
dowTues:n__hrs__from__sunrise:n__daylighthrs:dom	-2.664271	0.0077231
ambient__lag720:hod:dow^4	-2.651041	0.0080322
ambient__lag120:n__daylighthrs	2.647764	0.0081104
ambient__lag360:dow.C	-2.616284	0.0088975
ambient__lag360	-2.603833	0.0092272
ambient__lag720:n__hrs__from__sunrise	-2.508396	0.0121377
dowThurs:n__hrs__from__sunrise:dom	2.486938	0.0128947
dowSun:n__hrs__from__sunrise:n__daylighthrs:dom	-2.484041	0.0130001

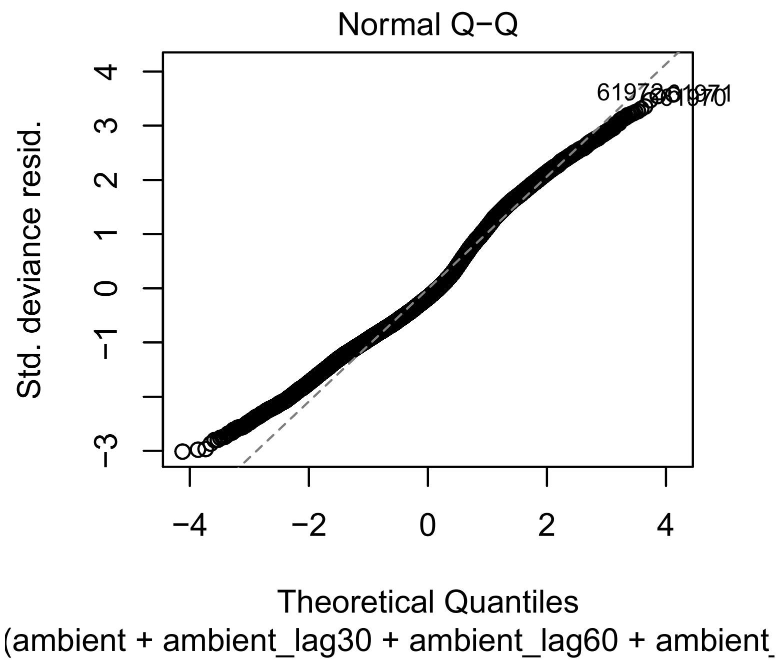
Elec-full

Formula

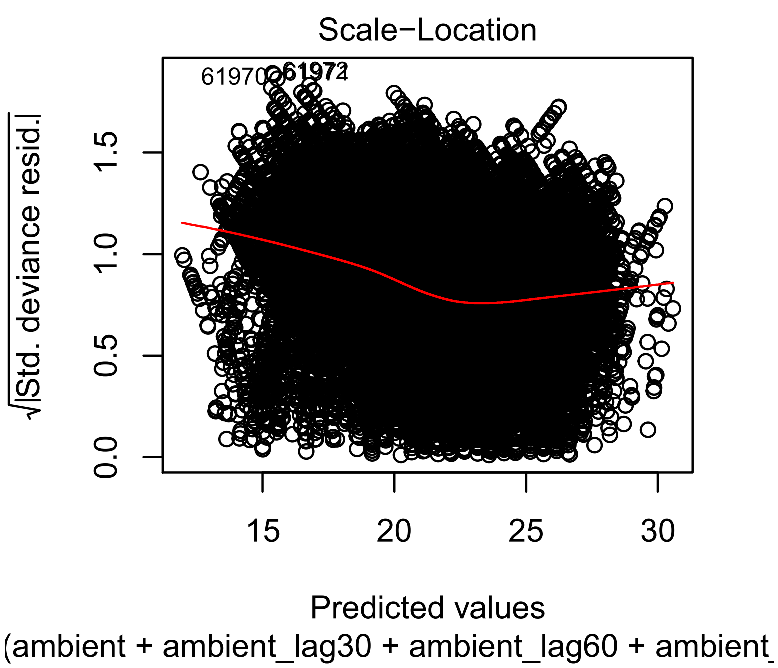
temp ~ (ambient + ambient_lag30 + ambient_lag60 + ambient_lag120 + ambient_lag360 + ambient_lag720) * (hod * dow + n_hrs_from_sunrise * n_daylighthrs) + hod:(n_hrs_from_sunrise + n_daylighthrs) + (dow:dom):(n_hrs_from_sunrise * n_daylighthrs) + (dow:dom):(ambient_lag1440 + ambient_lag2880) + hod

Goodness of fit





Normal Q−Q
Std. deviance resid.
Theoretical Quantiles
(ambient + ambient_lag30 + ambient_lag60 + ambient_



Scale−Location
√|Std. deviance resid.|
Predicted values
(ambient + ambient_lag30 + ambient_lag60 + ambient_

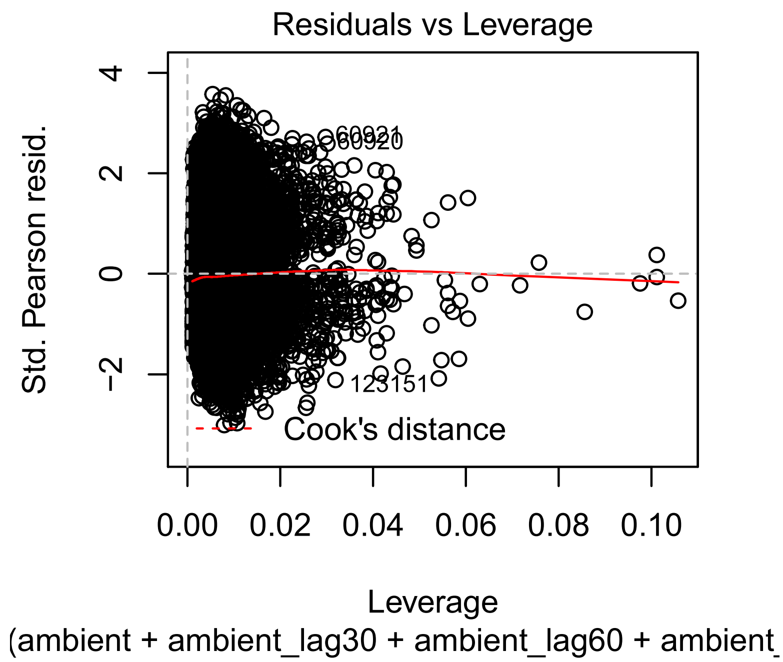


Table 5: Most significant terms (first 50) for 'elec_full' GLM

term	t value	Pr(>|t|)
dowThurs:n_hrs_from_sunrise:dom	23.566678	0.0000000
dowThurs:n_hrs_from_sunrise:n_daylighthrs:dom	-23.386464	0.0000000
dowFri:n_hrs_from_sunrise:n_daylighthrs:dom	-22.796976	0.0000000
dowFri:n_hrs_from_sunrise:dom	22.608490	0.0000000
dowTues:n_hrs_from_sunrise:dom	21.083482	0.0000000
dowTues:n_hrs_from_sunrise:n_daylighthrs:dom	-21.075474	0.0000000
hod:n_daylighthrs	-18.184777	0.0000000
n_hrs_from_sunrise:n_daylighthrs	17.034747	0.0000000
hod	16.569464	0.0000000
dowMon:n_hrs_from_sunrise:n_daylighthrs:dom	-15.198218	0.0000000
n_hrs_from_sunrise	-14.881986	0.0000000
dowWed:n_hrs_from_sunrise:dom	14.858997	0.0000000
dowWed:n_hrs_from_sunrise:n_daylighthrs:dom	-14.492776	0.0000000
dowMon:n_hrs_from_sunrise:dom	14.304994	0.0000000
ambient_lag720:n_hrs_from_sunrise	-14.303064	0.0000000
dowSat:n_hrs_from_sunrise:dom	13.721707	0.0000000
dowSat:n_hrs_from_sunrise:n_daylighthrs:dom	-13.064464	0.0000000
dowMon:dom:ambient_lag2880	12.688243	0.0000000
dowSun:n_daylighthrs:dom	-12.190691	0.0000000
dowTues:n_daylighthrs:dom	-11.921185	0.0000000
dowMon:n_daylighthrs:dom	-11.702033	0.0000000
ambient_lag720:n_daylighthrs	10.738356	0.0000000
ambient_lag720:n_hrs_from_sunrise:n_daylighthrs	10.662302	0.0000000
dowWed:n_daylighthrs:dom	-9.750347	0.0000000
hod:dow.L	-9.352217	0.0000000
ambient_lag720	-9.099318	0.0000000

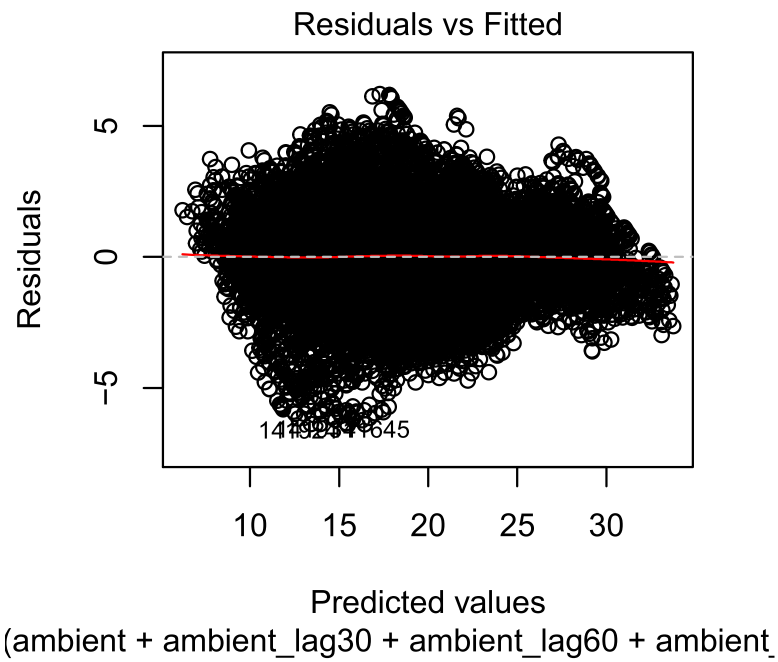
term	t value	Pr(>|t|)
dowFri:n_daylighthrs:dom	-9.001530	0.0000000
ambient_lag720:hod	8.669372	0.0000000
hod:n_hrs_from_sunrise	-8.667876	0.0000000
dowSun:dom:ambient_lag1440	8.315329	0.0000000
n_daylighthrs	7.971806	0.0000000
dow.L	7.881714	0.0000000
hod:dow.C	-7.176093	0.0000000
dowFri:dom:ambient_lag1440	6.272606	0.0000000
dowTues:dom:ambient_lag1440	6.077004	0.0000000
dowSat:dom:ambient_lag1440	5.968163	0.0000000
ambient_lag360:n_daylighthrs	5.536431	0.0000000
ambient_lag360:hod:dow^5	5.177839	0.0000002
dowThurs:dom:ambient_lag2880	4.971470	0.0000007
dow.Q	-4.950849	0.0000007
dowWed:dom:ambient_lag1440	4.459576	0.0000082
dowSun:n_hrs_from_sunrise:n_daylighthrs:dom	-4.417083	0.0000100
ambient_lag720:dow.L	-4.364100	0.0000128
hod:dow^5	-4.319257	0.0000157
dowSat:n_daylighthrs:dom	-3.860155	0.0001136
dowSun:n_hrs_from_sunrise:dom	3.848133	0.0001193
dowSat:dom:ambient_lag2880	-3.847985	0.0001194
ambient_lag360	-3.786726	0.0001530
ambient:n_daylighthrs	3.719423	0.0002001
ambient_lag720:dow^5	-3.689645	0.0002250

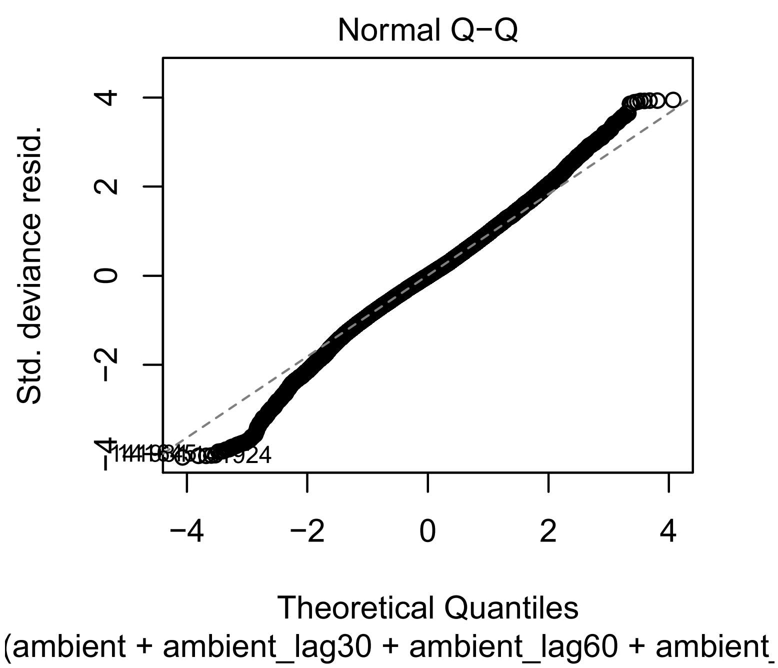
LPG-basic

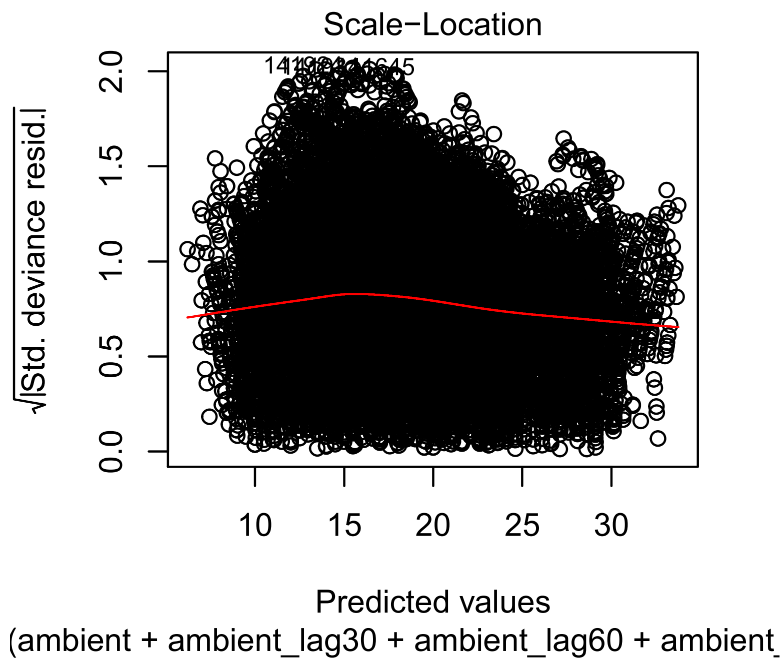
Formula

temp ~ (ambient + ambient_lag30 + ambient_lag60 + ambient_lag120 + ambient_lag360 + ambient_lag720) * (hod * dow + n_hrs_from_sunrise * n_daylighthrs) + hod:(n_hrs_from_sunrise + n_daylighthrs) + (dow:dom):(n_hrs_from_sunrise * n_daylighthrs) + (dow:dom):(ambient_lag1440 + ambient_lag2880) + hod

Goodness of fit







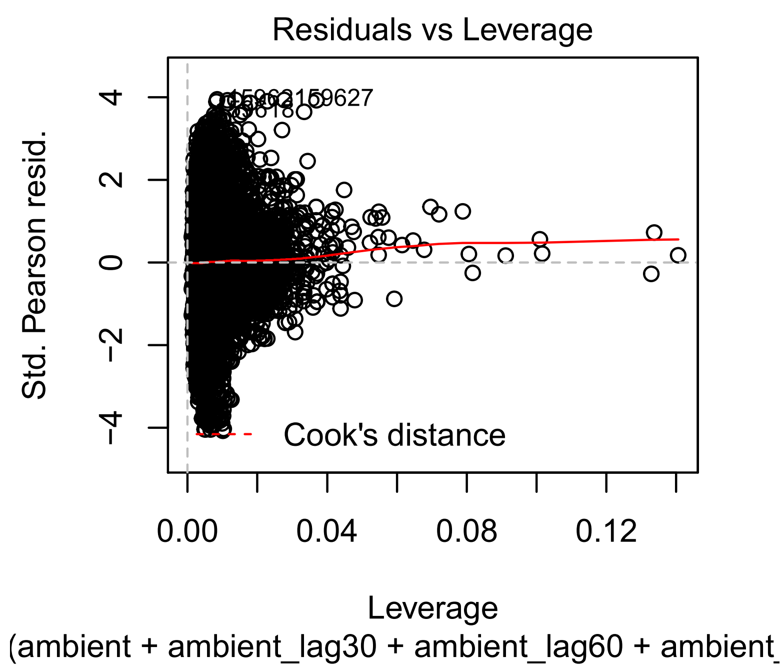


Table 6: Most significant terms (first 50) for 'lpg_basic' GLM

term	t value	Pr(>|t|)
hod:n_daylighthrs	35.802200	0.0000000

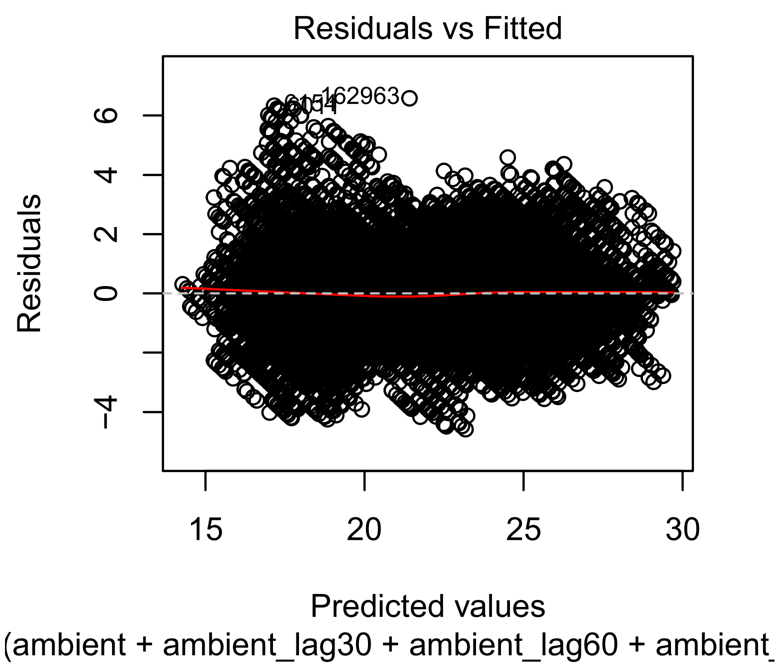
term	t value	Pr(>|t|)
n__daylighthrs	-35.653078	0.0000000
hod	-34.595593	0.0000000
(Intercept)	33.025591	0.0000000
n__hrs__from__sunrise:n__daylighthrs	-32.146595	0.0000000
n__hrs__from__sunrise	30.634260	0.0000000
ambient__lag720:n__hrs__from__sunrise	20.227944	0.0000000
ambient__lag720:hod	-18.420922	0.0000000
ambient__lag720	13.318059	0.0000000
dowSun:n__daylighthrs:dom	-13.191219	0.0000000
dowSat:n__daylighthrs:dom	-13.022012	0.0000000
dowSat:dom:ambient__lag1440	11.953494	0.0000000
dowFri:dom:ambient__lag1440	11.246192	0.0000000
ambient__lag360:n__hrs__from__sunrise:n__daylighthrs	10.318047	0.0000000
hod:n__hrs__from__sunrise	-9.865337	0.0000000
ambient__lag720:n__hrs__from__sunrise:n__daylighthrs	-9.349690	0.0000000
ambient:n__daylighthrs	-7.619992	0.0000000
ambient	7.511715	0.0000000
ambient__lag720:n__daylighthrs	-7.018410	0.0000000
ambient__lag360	6.873556	0.0000000
dowSun:dom:ambient__lag2880	6.767867	0.0000000
ambient__lag360:n__daylighthrs	-6.727112	0.0000000
dowThurs:n__daylighthrs:dom	-6.460540	0.0000000
dowFri:n__daylighthrs:dom	-6.338383	0.0000000
dow.Q	5.973452	0.0000000
dowMon:n__hrs__from__sunrise:n__daylighthrs:dom	-5.962247	0.0000000
dowThurs:dom:ambient__lag1440	5.904788	0.0000000
dowWed:dom:ambient__lag2880	5.605520	0.0000000
ambient__lag360:dow^6	-5.520336	0.0000000
dowMon:n__daylighthrs:dom	5.334716	0.0000001
ambient__lag360:dow.L	-5.291350	0.0000001
ambient__lag120:dow.Q	5.262761	0.0000001
ambient__lag360:hod:dow.L	5.202392	0.0000002
ambient__lag120:hod:dow.Q	-5.181890	0.0000002
ambient:hod	-5.121806	0.0000003
dowFri:dom:ambient__lag2880	-5.033285	0.0000005
ambient__lag360:n__hrs__from__sunrise	-4.778529	0.0000018
ambient__lag360:hod:dow^5	4.740126	0.0000021
ambient__lag120:n__hrs__from__sunrise:n__daylighthrs	-4.533501	0.0000058
dowWed:dom:ambient__lag1440	-4.501233	0.0000068
dowSun:n__hrs__from__sunrise:dom	-4.470037	0.0000079
dowFri:n__hrs__from__sunrise:n__daylighthrs:dom	-4.358980	0.0000131
ambient__lag720:hod:dow^6	-4.194190	0.0000275
ambient__lag360:hod:dow^6	4.182935	0.0000289
dowSun:n__hrs__from__sunrise:n__daylighthrs:dom	3.899385	0.0000967
ambient:dow.Q	-3.848762	0.0001191
dowMon:n__hrs__from__sunrise:dom	3.833993	0.0001264
ambient__lag120:n__daylighthrs	3.799251	0.0001455
ambient__lag120:n__hrs__from__sunrise	3.732755	0.0001899
ambient__lag360:hod:dow.Q	3.657308	0.0002555

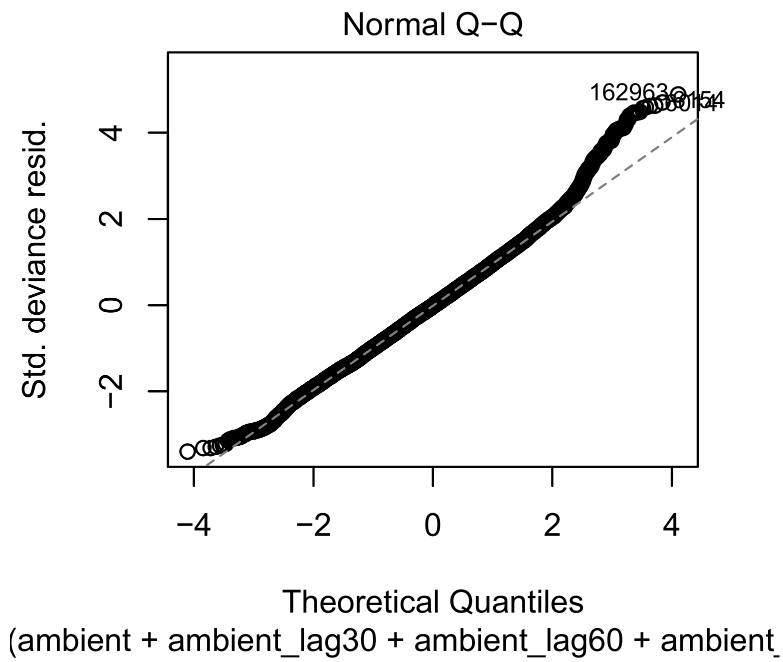
LPG-full

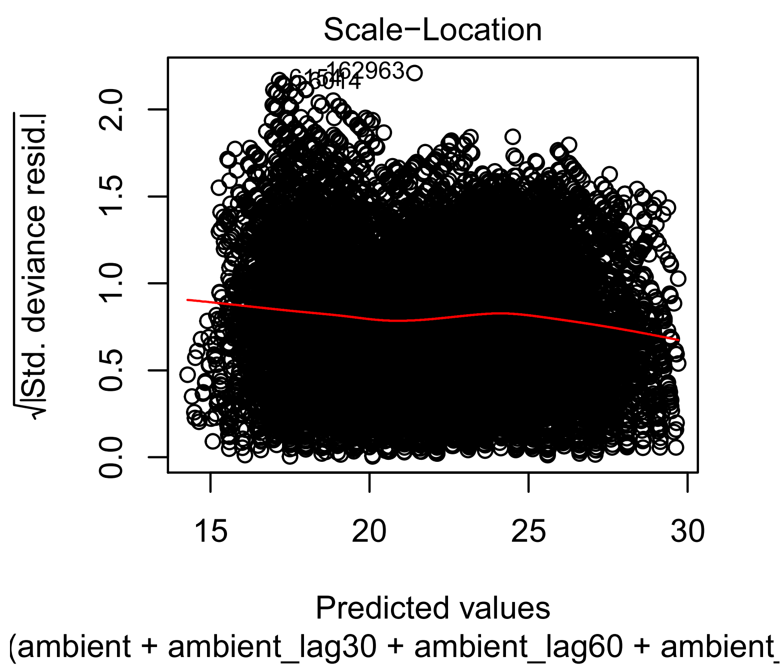
Formula

temp ~ (ambient + ambient_lag30 + ambient_lag60 + ambient_lag120 + ambient_lag360 + ambient_lag720) * (hod * dow + n_hrs_from_sunrise * n_daylighthrs) + hod:(n_hrs_from_sunrise + n_daylighthrs) + (dow:dom):(n_hrs_from_sunrise * n_daylighthrs) + (dow:dom):(ambient_lag1440 + ambient_lag2880) + hod

Goodness of fit




Normal Q−Q
Std. deviance resid.
Theoretical Quantiles
(ambient + ambient_lag30 + ambient_lag60 + ambient_
162963


Scale−Location
√|Std. deviance resid.|
Predicted values
(ambient + ambient_lag30 + ambient_lag60 + ambient_
162963

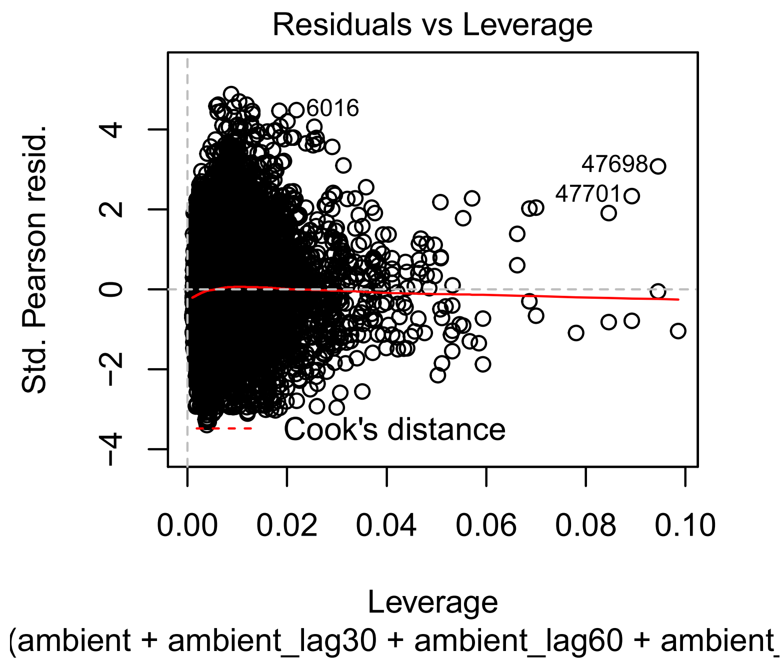


Table 7: Most significant terms (first 50) for 'lpg_full' GLM

term	t value	Pr(>|t|)
dowMon:n_hrs_from_sunrise:n_daylighthrs:dom	-26.984411	0.0000000
dowMon:n_hrs_from_sunrise:dom	26.826399	0.0000000
hod:n_daylighthrs	-25.510158	0.0000000
dowSat:n_hrs_from_sunrise:dom	23.795994	0.0000000
hod	23.592045	0.0000000
n_hrs_from_sunrise:n_daylighthrs	23.559860	0.0000000
dowSat:n_hrs_from_sunrise:n_daylighthrs:dom	-23.531087	0.0000000
dowFri:n_hrs_from_sunrise:n_daylighthrs:dom	-22.071918	0.0000000
dowTues:n_hrs_from_sunrise:dom	21.870348	0.0000000
dowFri:n_hrs_from_sunrise:dom	21.795684	0.0000000
dowTues:n_hrs_from_sunrise:n_daylighthrs:dom	-21.752392	0.0000000
dowSun:n_hrs_from_sunrise:dom	21.155514	0.0000000
dowSun:n_hrs_from_sunrise:n_daylighthrs:dom	-20.839327	0.0000000
n_hrs_from_sunrise	-20.812475	0.0000000
dowThurs:n_hrs_from_sunrise:dom	17.696957	0.0000000
dowThurs:n_hrs_from_sunrise:n_daylighthrs:dom	-17.340440	0.0000000
hod:n_hrs_from_sunrise	-17.121212	0.0000000
ambient_lag720:n_daylighthrs	13.748925	0.0000000
ambient_lag720:n_hrs_from_sunrise	-13.452678	0.0000000
hod:dow.C	-11.936919	0.0000000
ambient_lag720	-11.862190	0.0000000
dowWed:n_hrs_from_sunrise:dom	11.374411	0.0000000
dowWed:n_hrs_from_sunrise:n_daylighthrs:dom	-11.053274	0.0000000
ambient_lag720:hod	9.671647	0.0000000
ambient_lag720:dow.L	-9.669801	0.0000000
ambient_lag720:hod:dow.L	9.512872	0.0000000

term	t value	Pr(>|t|)
ambient_lag720:n_hrs_from_sunrise:n_daylighthrs	8.845377	0.0000000
ambient_lag360:n_daylighthrs	8.806191	0.0000000
dowMon:dom:ambient_lag2880	8.326623	0.0000000
ambient_lag360:n_hrs_from_sunrise:n_daylighthrs	7.448964	0.0000000
dow.C	7.250786	0.0000000
n_daylighthrs	7.033602	0.0000000
dowThurs:n_daylighthrs:dom	-6.950054	0.0000000
ambient_lag360:n_hrs_from_sunrise	-6.754655	0.0000000
dowTues:dom:ambient_lag1440	6.558348	0.0000000
hod:dow.L	-6.048042	0.0000000
ambient_lag360	-5.864406	0.0000000
dowTues:n_daylighthrs:dom	-5.297128	0.0000001
dowMon:n_daylighthrs:dom	-5.213028	0.0000002
ambient_lag120:n_daylighthrs	5.000382	0.0000006
ambient_lag360:hod:dow.C	4.170056	0.0000306
ambient_lag720:dow.Q	-3.859783	0.0001138
dowSat:dom:ambient_lag2880	-3.817290	0.0001353
dowWed:dom:ambient_lag1440	3.785056	0.0001540
ambient_lag360:dow.C	-3.579118	0.0003454
ambient_lag120:dow.L	3.539932	0.0004010
dowSat:dom:ambient_lag1440	3.447554	0.0005666
dowThurs:dom:ambient_lag1440	3.375500	0.0007379
ambient_lag720:hod:dow.C	3.279994	0.0010395
dowFri:dom:ambient_lag1440	3.143551	0.0016711