ENERGY EFFICIENT RONDAVELS IN THE KRUGER NATIONAL GAME RESERVE, SOUTH AFRICA

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ABSTRACT

Unique huts are being used as guest lodges in the South African National Kruger Game Park. These are inspired by the rondavels (indigenous round thatched adobe building), but have been westernized by adding glazed window areas, higher cement block walls and asbestos fiber cement roofs. Serious overheating and overcooling occurs if the huts are not air-conditioned. The summer design day indoor temperature then remains above 27°C (81°F), while in winter it remains below 18°C (64°F) for 20 hours per day.

Tourist accommodation typically makes up 65% of the power consumption of camps. Where camps are not grid-connected this led to high costs. Various passive design alternatives have been simulated using the Quick program, developed by the University of Pretoria. A combination of envelope optimization, earth connected ventilation pipes and ceiling fans led to thermal comfort while cost-effectively reducing peak demand by 30% and consumption by 33% without impairing the architecture.

This paper shows that indigenous designs are a good starting point throughout the world (no matter if it is Africa, Mexico,...). They are a "window" to designing low embodied energy to passive solar design for their particular region!

INTRODUCTION

Visiting the Kruger National Park to "hunt" the Big Five is an unforgettable experience. Part of this is the climate and the unusual architecture of rondavels. These traditional buildings were originally windowless round huts with low mud walls (adobe or wattle- and- daub) topped by conical thatched roofs.

However, the progressive introduction of concrete block walls to increasing wall heights, glazed window-areas and the use of asbestos reinforced cementitious roofing forfeited the benefits of low embodied energy and passive solar design. This led to the need for air-conditioning units, which caused high consumption and high peak demands of expensive electricity. About two thirds of the Skukuza camp energy bill is attributed to guest accommodation.

Skukuza is the largest camp in the two million hectare game reserve which is about equal to the area of Massachusetts. It is approximately 500km east of Pretoria, sharing the eastern boundary with Moçambique.

The annual rainfall of 680mm mostly occurs during summer (December, January) leading to hot-humid conditions. During the dry winters, animals seek the water holes and are more easily visible because of the then shorter grass. The mean daily dry bulb temperature amplitude is 14K (25.2°F), with the largest swing during June, July. Winter nights are wonderfully clear, starry and still. The haunting jackal's call and the ominous lion's roar make their presence felt. On the eastern horizon the Lebombo range is penetrated by east bound rivers crossing the broad Sul do Save footvalley before discharging into the warm Agulhas current of the Indian ocean.

The northern tip of the reserve lies on 22°20' southern latitude - well inside of the Ecliptic of Capricorn (23°30'S), and closer to the equator than Rio de Janeiro. On the Southern boundary the Crocodile River reaches 25°32' southern latitude, which is about equidistant to the northern latitude of Brownsville. Skukuza lies on 25° S, and is only 700m above sea level.

INDIGENOUS RONDAVEL

The word "Rondavel" is probably derived from the Latin root "round" and is an apt description of the traditional climate-adapted 3,600 to 6,000mm diameter hut consisting of a circular 1,200 to 1,500mm high mud construction wall supporting a conical grass thatched roof. This geometry closely approximates the hemispherical Zulu hut but has the advantage that, the thatch does not touch the ground, thereby reducing risks of rot, fire and termites. The conical roof with a slope of 36° to 45° has a thickness of 150mm and consists of reedy type grass, less than a pencil thick and 1,200 to 2,000mm long. It has good insulation values. The thatch is stitched to circular laths supported by radial rafters, either resting on the wall or peripheral posts. The roof overhang serves to shade the walls and also protects them against erosion by rain. There are no gutters.

The traditional rondavel has no windows, light being provided by the door opening during the day and a wood fire at night. Fire was also useful against mosquitoes and other insects entering through the ventilation slit normally left between the top of the wall and the roof soffit. All building materials were harvested nearby in the veld. Hut building was a community ritual. After the death of its inhabitant the hut was left to decay, gradually returning to earth. This tradition required very little embodied energy and had little environmental impact.

Temperature measurements in traditional rondavels undertaken by the author in the Middelburg area yielded an amplitude ratio of 0.3 of the outdoor dry bulb temperature swing, which is quite good a result. However, the delta T in summer is 1.5K, which is not so good. So the romantic appeal of indigenous architecture has its limits.

MODERN RONDAVELS

Figure 1. Modern rondavel

Design

Most contemporary tourists would hardly be prepared to stoop at the entrance door, stay in a windowless room with dark brown mud-plastered walls and floors, or sleep on the floor on a thin woven grass mat in a smoke filled room without any ablutions.

The gradual introduction of standard rectangular beds, closets, baths, showers, vanity cabinets etc brought so much conflict with the circular shape that this was often abandoned in favor of a rectangle. This led to enlarged surface-to-volume ratio, and it necessitated a revised roof shape, often a replacement by standard hipped asbestos fiber reinforced sheets. Wall heights were increased to at least 2 100 and glazed windows with insect screened openable sections followed. Walls were built of concrete blocks with cement stucco and white wash.

South Africa's standard power is 220 Volt at 50Hz. A modern hut would typically have four 60W incandescent lights, a 200W refrigerator, a 100 litre water heater with a 3.10kW element, a 120W ceiling fan and miscellaneous plugs for TV, hair dryers etc. The resulting indoor temperature in passive mode is outside the summer and winter thermal comfort range. See figures 2 and 3.

Consequently a 3.5kW air-conditioning unit has to be installed. This produces a peak demand on the system because tourists act in a synchronised manner. The arrive in air conditioned automobiles and tend to have demanding comfort expectations.

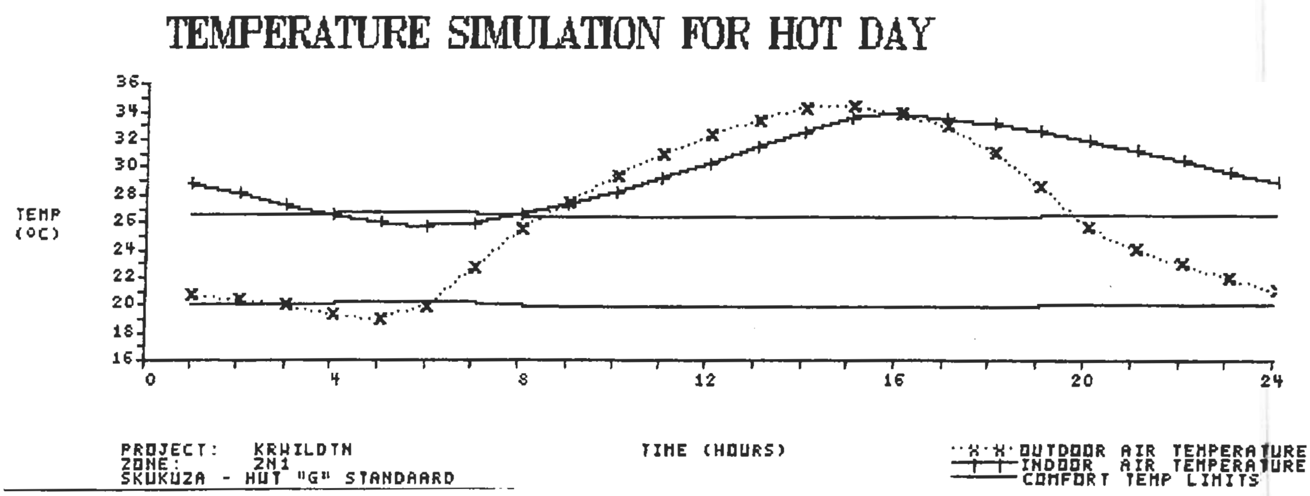

Figure 2. Status quo for summer conditions

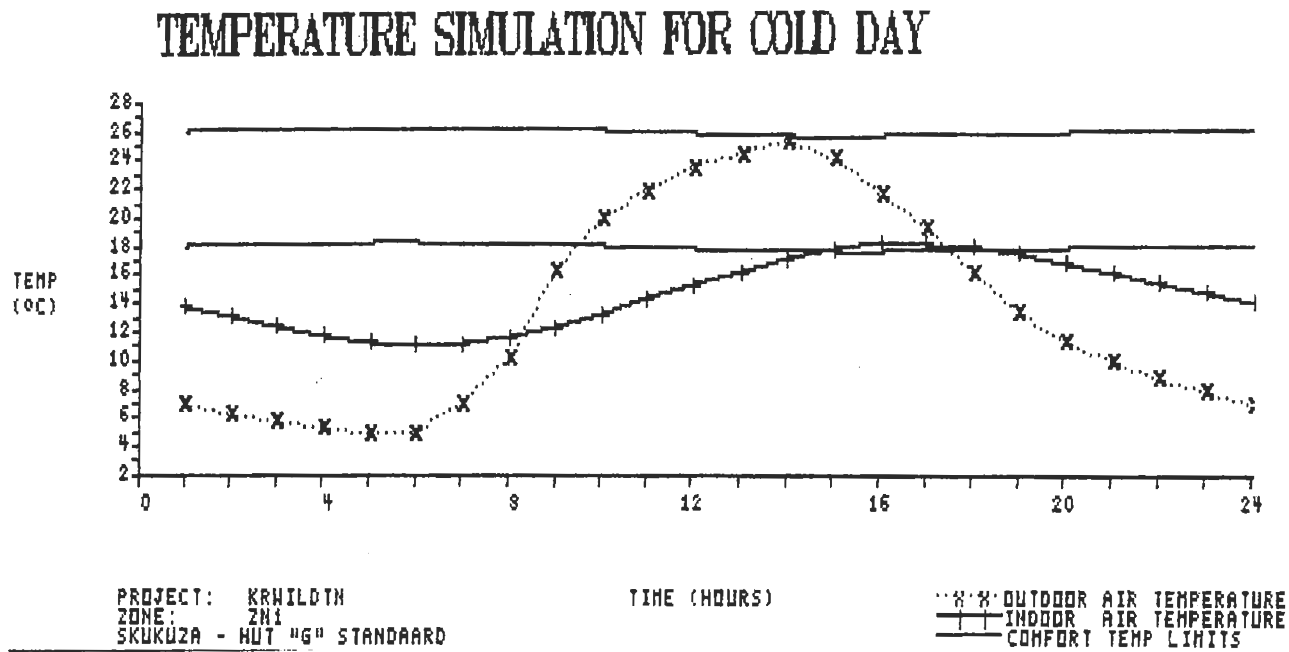

Figure 3. Status quo for winter conditions

In addition to the electrical peak demand, consumption is also considerable in an area where electricity is expensive by South African standards.

Use pattern

There is a seasonal shift in the use pattern as follows.

Use	summer	winter
Arrival	12:00-16:00	12:00-16:00
Game viewing	16:00-17:30	16:00-17:00
Bath, supper	17:30-20:00	17:00-19:00
Relax	20:00-22:00	19:00-22:00
Sleep	22:00-06:00	22:00-07:00
Breakfast	06:00-07:00	07:00-7:30
Game viewing	07:00-10:00	07:30-9:00
Relax	10:00-16:00	09:00-17:30

IMPROVED RONDAVELS

Design climate

In contrast with the convention of using the TMY or degree-days, it is standard practice in South Africa to use the "design day" method. This is argued on the grounds of the probability levels of coincidence of weather conditions [1]. For hot conditions this is the **combined** probability effect of solar radiation, low temperature radiation exchange, dry bulb temperature and wind speeds, whereas for cold conditions it is the daily minimum temperatures and wind speed. This procedure takes account of the characteristically large diurnal variations in air temperature and radiation, abundance of sunshine and the predominantly heavy weight construction, as well as the probability of runs of successive hot or cold days (spells). The design day weather data assume the previous day to be of the same conditions.

Hot and cold design day data have been produced for all representative stations in Southern Africa at the 10%, 5% and 2.5% probability levels. The 10% probability level represents the mean of the 10% extreme hot and 10% extreme cold days. These are expected to be exceeded on 10 to 15 days per year. Similarly the 5% and 2.5% levels have been obtained representing design data of increasing stringency. While there are standards for commercial buildings [2], there are no energy standards or codes for housing in South Africa.

THERMAL COMFORT

Following Szokolay [3] the summer and winter thermal comfort zones were calculated for a population acclimatized to local conditions (figure 4). It appears that the outdoor climate is overly hot-humid from October to April. While the over-cooled period represents a relatively minor problem from the passive solar design point of view, the hot-humid problem is not so tractable.

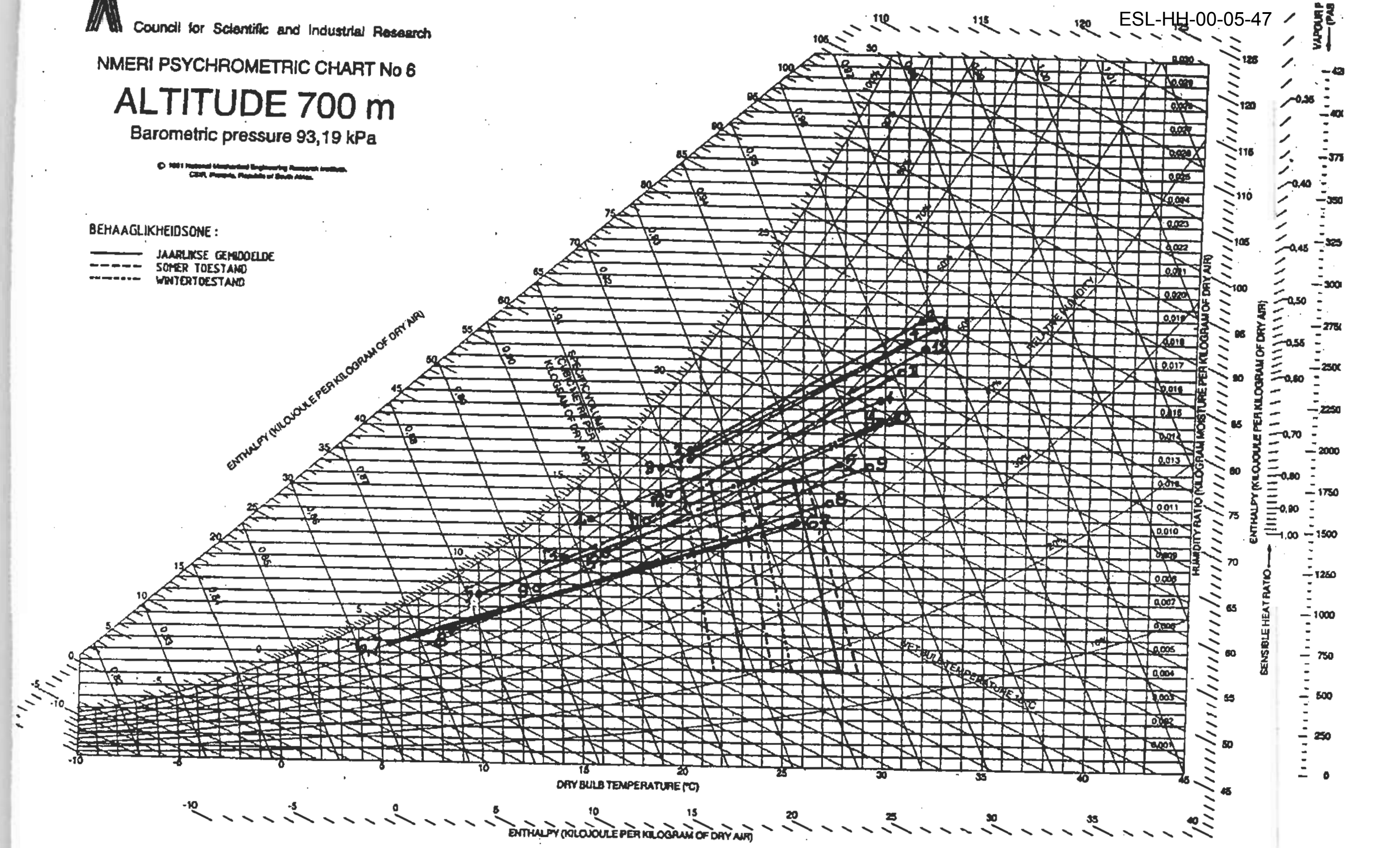

Figure 4. Skukuza

SIMULATION PROGRAM

"Quick" was originally developed by the Center for Experimental and Numerical Thermoflow at the Department of Mechanical Engineering, University of Pretoria, under leadership of Professor Eddie Mathews. It has been validated for South African conditions, is user-friendly and sufficiently accurate for most design evaluations.

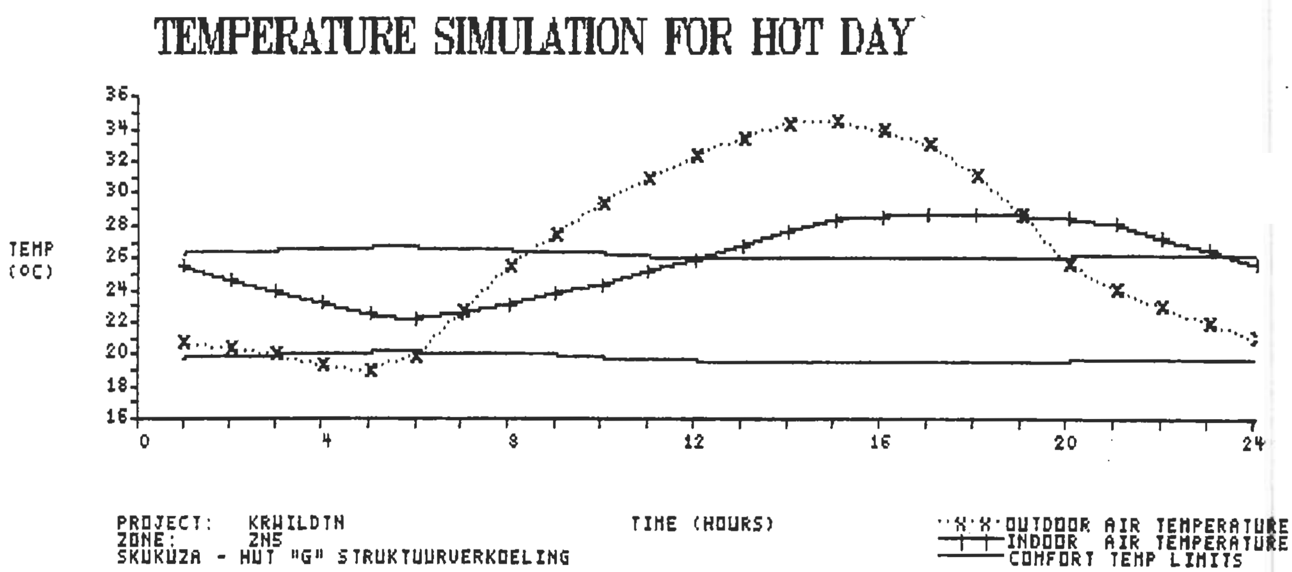

Figure 5. Structural night air cooling with cavity wall for summer condition

ALTERNATIVES

Twenty-one alternative designs were modeled, starting with the status-quo (figs. 2 & 3) until maximum indoor thermal comfort was reached in both summer and winter. A selection is illustrated below. [4]

Structural night air cooling with cavity wall

This leads to a 50% thermal improvement in summer (fig. 5) and almost acceptable conditions in winter (fig. 6).

Elimination of west window

The summer maximum is reduced (fig. 7) while making little difference in winter (fig. 8).

Cavity filled with 50mm polystyrene plus 80% direct evaporative cooling

Acceptable summer (fig. 9) and winter (fig. 10) conditions are achieved, but at a cost.

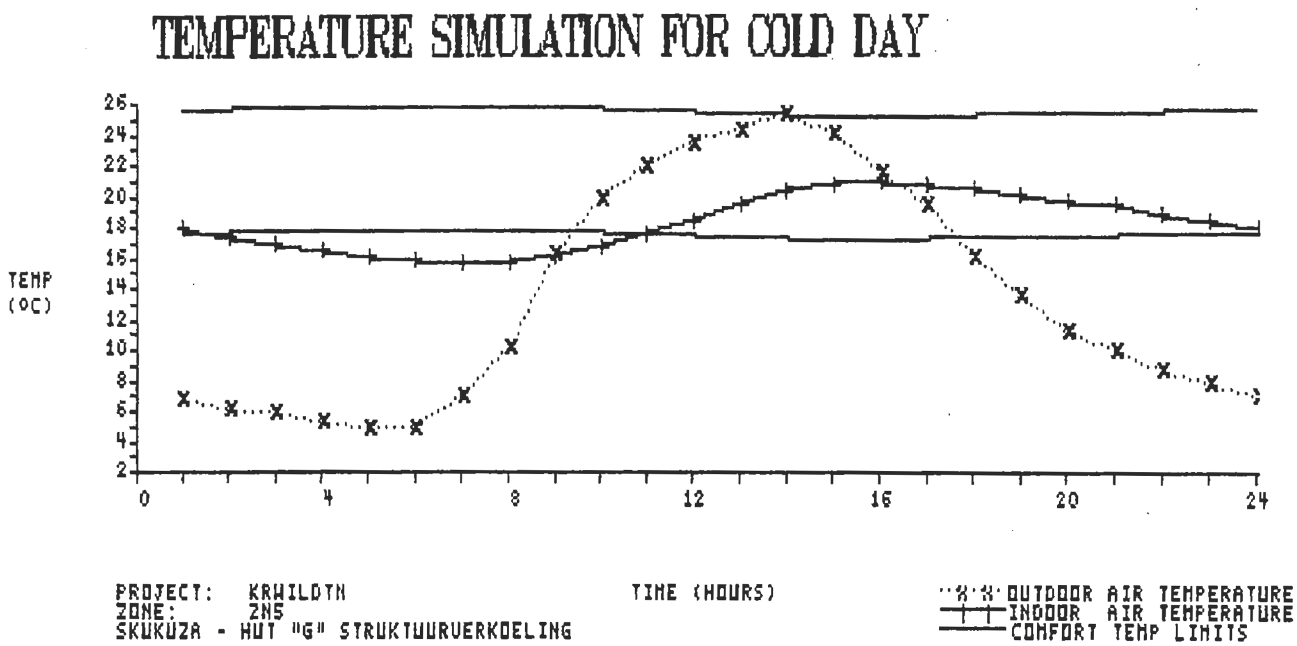

Figure 6. Structural night air cooling with cavity wall for winter conditions

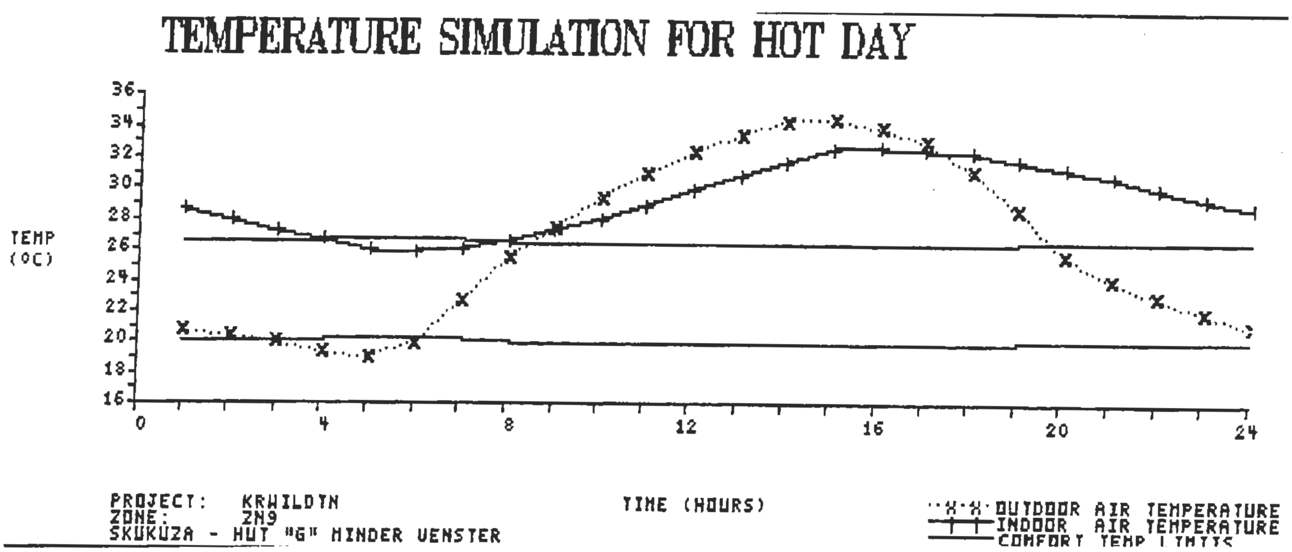

Figure 7. Elimination of west window for summer conditions

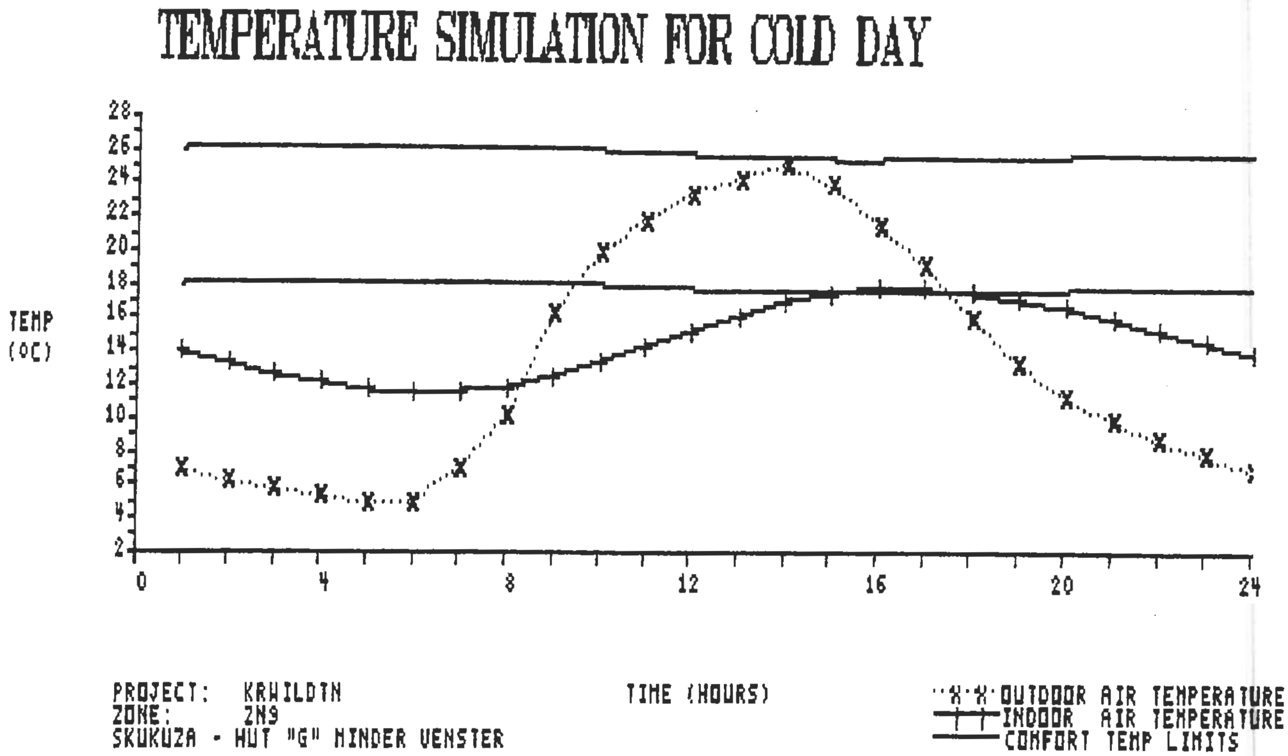

Figure 8. Elimination of west window for winter conditions

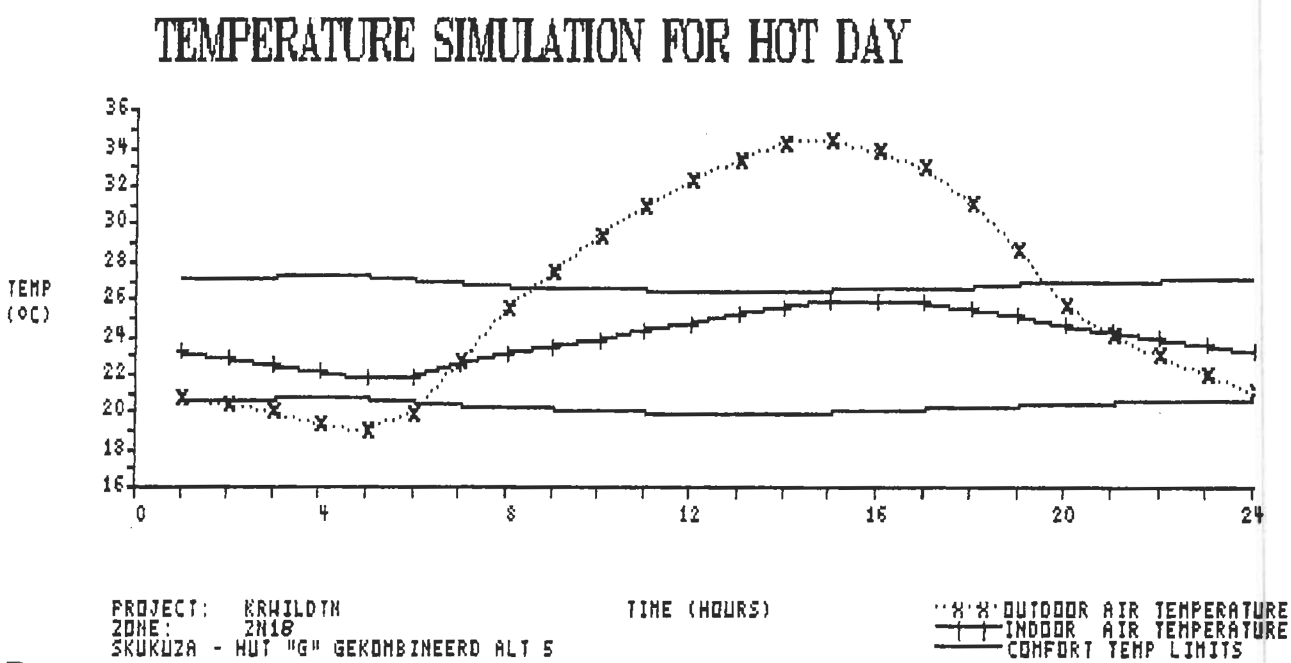

Figure 9. Cavity filled with 50mm polystyrene plus 80% direct evaporative cooling for summer conditions

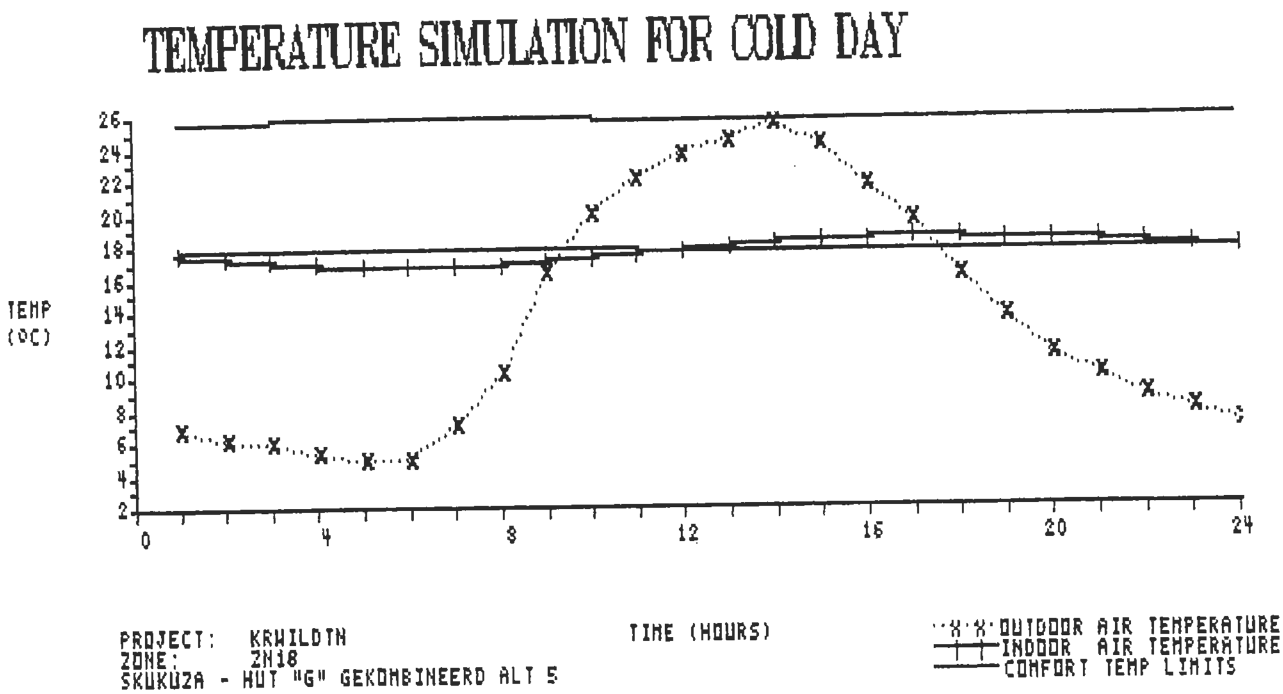

Figure 10. Cavity filled with 50mm polystyrene plus 80% direct evaporative cooling for winter conditions

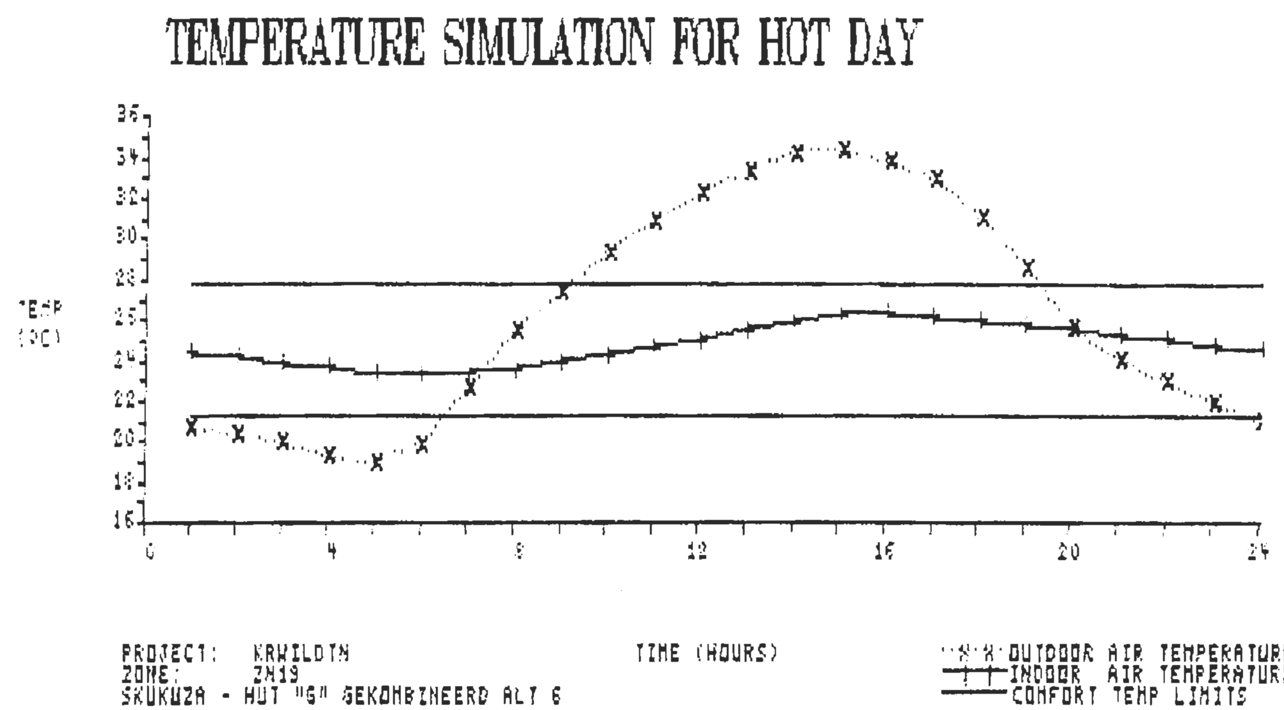

Figure 11. Underground air pipe, ceiling fan for summer conditions

Underground air pipe, ceiling fan

Comfort is maintained (fig. 11) cost effectively. The absorptivity of the exterior finish is reduced from 30% to 18.5% (ASTM E - 892 - 82) while the emittance remains 90% (ASTM E - 408 -71). A variable speed fan produces air speed from 0.5m/s to 1.5m/s (100 to 150 ft/minute) through a 10m, 250 ømm underground pipe.

RESULTS

After passive design changes to the envelope (reduced wall height, elimination of west window, reflective white exterior paint, weatherization, perimeter insulation) and reduction of interior gains (incandescents replaced by CFLs) and underground air supply system provides comfort. The peak demand is reduced by 30% and the consumption by 33%.

CONCLUSION, FURTHER WORK

The above design changes do not include (improved) insulation to the electrical water heater, insulation to the hot water pipes or - probably the better option - domestic solar water heaters. Passive thermal design can achieve thermal comfort while saving energy costs and retaining the architectural appeal of the traditional rondavel.

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