Towards Standardising Building Rural Clinics: Energy Requirements

Stefan Szewczuk

Abstract— Recognising that historical funding models have entrenched inequity and undermined affordability of healthcare services in South Africa, the National Department of Health is introducing the National Health Insurance scheme to integrate healthcare services. This will be heralded by a renewed focus on primary health care provision and will be accompanied by an initiative to re-engineer primary health care services. Major implications, such as shifting to increased community outreach services (as opposed to facility-based services); emerging requirements for information networks (for NHI management) are foreseen. As infrastructure is integral to the delivery of health care services, these organisational transformations provide an extraordinary opportunity for Science, Engineering & Technology (SET) input into the strategic planning, design, specification, equipping, and commissioning of primary healthcare facilities. This paper discusses the available building technologies including conventional (brick and mortar) and Innovative Building Technologies (IBTs) and alternative off-grid services technologies (energy, water, and sanitation). The paper discusses the energy requirements of a conceptual design for a generic, basic rural clinic.

***Index Terms*— Hybrid mini-grid energy, Innovative Building Technologies, Rural clinics, Standardising Clinics, Solar Energy, Wind Energy**

1 INTRODUCTION

Primary healthcare services are the kingpin of healthcare services in South Africa. It is recognised that prioritisation of care at this level of service is uniquely suitable to promote good health, prevent ill-health and avert demand for services at higher, more expensive, levels of care. In order for South Africans to benefit in this way, primary healthcare services need to be inclusive, accessible, affordable and high quality.

Primary healthcare service delivery is severely hampered by lack of, and poor quality infrastructure. In many cases the physical infrastructure at clinics is old, inadequate and in some cases not suitable for use. The provision of services, such as water, sanitation and electricity, is in many cases not adequate, especially in rural areas of South Africa.

In addition to this, no standardised clinic design and lifecycle management tools currently exist. This results in poor infrastructural investment decision making, problematic procurement processes and practices and poor maintenance of existing facilities. Re-engineering of primary healthcare as the main mechanism of healthcare service delivery requires urgent intervention at the infrastructure level.

S Szewczuk, Council for Scientific and Industrial Research (CSIR), Built Environment, PO Box 395 Pretoria, 0001 , South Africa
e-mail: sszewczuk@csir.co.za.

There is no accurate data on the number of clinics in South Africa, but the available indication is a number of more than 3500.

2 PATIENT FLOW PATTERNS

Since there is no standardised rural clinic design, a review was done on available literature on restructuring South Africa's Primary Health Care. It became evident that the various Provinces have developed their own design guidelines for their respective health facilities [1, 2, 3]. An attempt was made by the CSIR to understand patient flow patterns into and out of a typical basic clinic. A further attempt was made to optimise patient flow patterns, recognising the need for also optimising the operational aspect of a basic clinic and the need for future expansion [4].

A general patient flow pattern was established (Figure1).

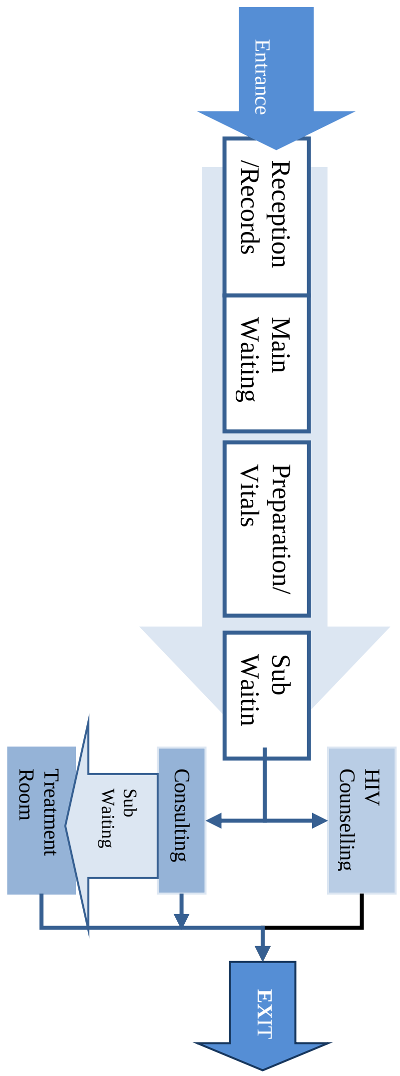

Fig.1. General patient flow diagram

Patients enter the clinic site through a controlled entrance at the security guardhouse. From here they proceed to the front entrance of the clinic building. Upon entering, patients register at the front reception desk, after which they remain in the main waiting area until called by a nurse, who, where necessary, takes the patients' details, blood pressure and possibly their weight. Patients required to give a urine sample for testing will use the paraplegic toilet adjacent to the urine sample room.

Having been attended to by the nurse, patients are directed to wait in the sub waiting area before proceeding to the main consulting rooms or the HIV counselling rooms.

designed to permit TB patients minimal interaction with other patients.

TB patients

TB patients go directly to the TB sub waiting area after registering at the reception desk. Once they are seen by the nurse, they will exit the building.

Emergency patients

Emergency patients arrive at the clinic and are immediately directed to the emergency room where they are attended to by the duty nurse, who may call for an ambulance to collect the patient.

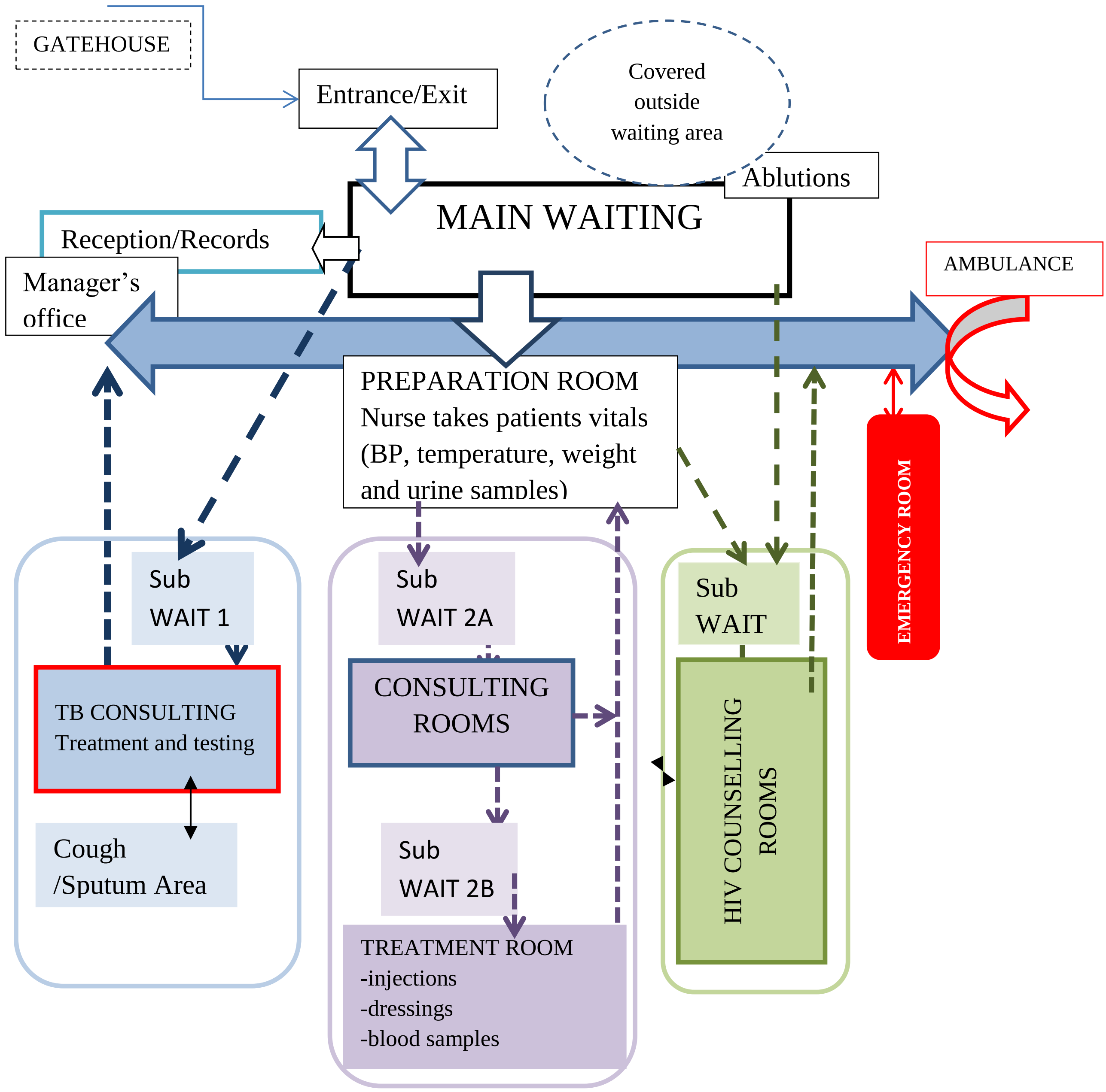

Fig. 2: Patient flow patterns for a basic clinic

After consultation or counselling, patients either go to the treatment room for further assistance or leave the building. Details are presented in Figure 2 [4]. The incidence of tuberculosis (TB) in South Africa is high and being a highly communicable disease the clinic should be

3 BUILDING TECHNOLOGIES

3.1 Introduction

Based on an improved understanding of patient flow patterns for an improved basic clinic, the design of a standardised clinic is possible. This section will discuss the options open for the types of building technologies that could be applied, namely conventional building technologies and innovative building technologies (IBTs).

IBTs offer the opportunity for buildings to be constructed from modular sections thereby reducing construction time. The CSIR is currently undertaking a study to establish whether the carbon footprint over the lifecycle of IBTs is less than that of conventional building technologies.

3.2 Conventional Building Technologies

Conventional building technologies are those widely used and familiar ‘brick and mortar’ building technologies and methods that meet the requirements of the National Building Regulations and Building Standards Act.

Conventional construction requires all the components to be delivered to the site and for the bulk of the construction work to occur on site regardless of weather conditions. The building work consists predominantly of wet trades, i.e., concrete and cement mortar. This slows down the building process since time has to be set aside for the cement and concrete to cure. Conventional building technologies also require sequential work, i.e., the work commences from the foundations up towards the roof assembly, and trades follow one another in a set sequence (concretor, brick layer, roof layer, plumber, electrician, plasterer, painter, etc.). This very often results in delays and damage to previous work (the plumber and electrician have to chase their pipes into the completed wall thereby damaging the quality of the brick or blockwork.

3.3 Innovative Building Technologies

Innovative Building Technologies (IBTs) are those technologies that do not meet the requirements of the National Building Regulations and Building Standards Act. However, the Act makes provision for non-standard building systems provided that it can be demonstrated that the non-standard building will perform as well as the standard building. The demonstration of this can occur through two methods namely either a rational design executed by a competent person, or an Agrément Certificate.

Since a rational design normally refers to the structural integrity of the method and excludes other assessment criteria such as moisture exclusion, most non-standard systems rely on Agrément certification.

The certification of a building system by Agremént requires the execution of various tests, which obviates the need for analysis using mathematical models or rational design/analysis approaches. The type and testing is dependent on the occupancy of the structure.

Agrément accreditation requires assessment based on the following criteria:

i) Structural strength and stability
ii) Condensation
iii) Durability
iv) Fire
v) Water penetration and damp proofing
vi) Thermal performance
vii) Acoustic Performance
viii) Quality management

Detailed information regarding Agrément’s assessment of these criteria is available from Agrément South Africa on request. www.agrement.co.za

3.4 Building and Thermal Performance

The materials to be used in the construction of a building are dependent on the building system employed. Since a novel/non-standard building technology is proposed to be used for the rapid deployment of clinics, a review of Agrément’s certified building systems was performed [5].

Based on the National Building Regulations, Agrément stipulate the type/class of occupancy that may be built using that technology. For the purposes of this paper, only the building systems that are certified for clinics, day clinics, health facilities and hospitals are discussed.

The foundation and roofing systems available are largely standard systems with limited variation from one system to the next. The focus of this discussion will therefore be on the walling systems.

For a rapid deployment of clinics, speed and ease of construction are paramount. The desired building technology would be one that constructs a building off site, under controlled plant conditions using light materials, and designed to the same codes and standards as conventionally built facilities. These technologies enable a building to be produced in ‘modules’ that when put together on site, reflect the identical design intent and specifications of the most sophisticated traditionally built facility.

The technologies generally used for modular buildings are insulated steel panels, insulated fibre cement panels, or concrete panels. Concrete panels are excluded due to their mass and difficulty in transporting.

Agrément describe the thermal performance of a building as the result of the process whereby the design, layout, orientation and construction materials of the building modify the prevailing outdoor climate to create the indoor climate[1]. Through computer simulation Agrément aim to arrive at an estimate of:

- The maximum indoor temperatures in summer
- The amount of energy required to maintain a minimum temperature (16°C) throughout the winter months.

Because temperature performance modelling is dependent on the climatic zone a structure is built in, and the type and size of the structure, Agrément base their temperature modelling on houses situated in:

- Cape Town;
- Durban; and
- Johannesburg.

The energy required for heating a house in to an indoor temperature of 16°C is determined for houses in Cape Town and Johannesburg.

The parameter used to compare the thermal performance of buildings and materials is the U-value. The ability of building components such as a wall and a window to transmit heat is expressed as the U-value of the component. In cold climates, building with low U-values will be easier to heat and to maintain at comfortable thermal levels than buildings with high U-values.

[1] Agrément Performance Criteria: Building and Walling Systems: Thermal Performance

Agrément evaluate the thermal performance of buildings with respect to the following criteria

a) Thermal acceptability

- A computer programme is used to calculate the maximum indoor temperatures likely to be experienced under typical hot summer conditions for the areas mentioned above.
- A computer program is used to calculate the energy required to maintain a minimum temperature of 16oC in winter for the areas mentioned above.

b) Health requirements

- Agremént's thermal performance criteria publication does not give detail on this requirement.

There are several commercially available computer programmes to calculate thermal performance of buildings. The CSIR evaluated a range of these computer programs as part of the process to obtain certification for use in South Africa by Agrément [6].

3.5 IBT Systems Categorisation

From the certified walling systems, it is suggested that the systems be classified as follows:

Structural frame with panel infill building system

The main system is:

i) Steel framing system

Structural Insulated Panels

Two main systems were identified:

i) Large wall sized panels
ii) Modular block sized panels

Frame and Cladding Systems

Two main systems were identified:

i) Steel frame
ii) Timber frame

A life cycle analysis on the use of Innovative Building Technologies for clinics should provide guidance as to which systems are the most appropriate to meet the growing demands for rural clinics.

4 ALTERNATIVE INFRASTRUCTURE SERVICE TECHNOLOGIES

4.1 Introduction

Buildings and their operations depend on the continued supply of services such as water, sanitation and electricity. However, service delivery failures do occur whether due to operational factors such as regular maintenance or system failure, or do to service protests.

Critical services such as primary health care rely on a stable service provision especially with regard to water, sanitation, electricity and the proper storage of drugs. Alternative infrastructure service technologies are technologies that can be implemented to provide alternative methods for securing a stable infrastructure service.

One of the strategies that can be employed to ensure an uninterrupted service is to reduce the building's exposure to municipal services. This will assist the building to adapt to major perturbations and events without a disruption in service delivery. Reducing the building's dependence on municipal services will also reduce the operational costs of the building.

4.2 Water Supply

Since the objective is to design an off-grid generic clinic, rainwater harvesting, is recommended. Rainwater harvesting is becoming popular again due to the inherent quality of rainwater and interest in reducing consumption of treated and expensive water. Rainwater has a nearly neutral pH, and is free from disinfection by-products, such as salts, minerals and other natural and man-made contaminants.

Advantages and benefits of rainwater harvesting are numerous [7]:

- The water is free; the only cost is for collection and use.
- The end use of harvested water is located close to the source, eliminating the need for complex and costly distribution systems.
- Rainwater provides a water source when groundwater is unacceptable or unavailable, or it can augment limited groundwater supplies.
- The zero hardness of rainwater helps prevent scale on appliances, extending their use.
- Rainwater eliminates the need for a water softener and the salts added during the softening process.
- Rainwater is sodium-free, important for persons on low-sodium diets.
- Rainwater is superior for landscape irrigation.
- Rainwater harvesting reduces flow to storm water drains and also reduces non-point source pollution.
- Rainwater harvesting helps utilities reduce the summer demand peak and delay expansion of existing water treatment and purification plants.
- Rainwater harvesting reduces consumers' utility bills.

In making use of rainwater harvesting the only energy requirement is to provide electricity for a water pump to pump water into a water tank to provide an adequate head to distribute water into the clinic

4.3 Sanitation

Lack of sanitation in health-care facilities is a more serious matter than lack of water supply. Many factors influence the choice of sanitation technology that meets the requirements for adequate sanitation at clinics, and these include:

- Cost effective provision of services and accessible to maintenance and servicing of the toilet by local community members.
- Management - the choice of system that is sustainable over the years.
- Use of the local contractors targeting youth and women.
- Sustainability of employment for the operational and maintenance.
- Improvements to health.

Anaerobic digesters are technologies that are used to convert organic waste into biogas. Biogas can be used as a fuel source. However it has been estimated that the volume of human waste that is produced by patients and visitors to a typical isolated rural clinic does not justify considering anaerobic digestion to produce biogas as a fuel as an option.

4.4 Electricity Generation & Estimated Costs

It is intended that all the power required to operate the clinic should be generated on site allowing the clinic to function off-grid. The design demand was calculated on maximum demand as if the clinic is being fully utilized throughout the day with minimal demand for electricity during the night and weekends.

Hybrid mini-grid systems are the favoured technology on which to base the design for an electricity generation system for a rural clinic. A hybrid mini-grid combines at least two different kinds of technologies for power generation and distributes the electricity to several consumers through an independent grid.

Thus, the mini-grid is supplied by a mix of renewable energy sources (RES) and a generator, generally powered by diesel, used as a back-up. It is a technology solution that provides high quality and reliable electricity for lighting, communications, water supply, or motive power. A hybrid power system functioning as an autonomous entity can provide almost the same quality and services as the national grid.

Moreover, with the proper arrangements, it is technologically possible to connect a mini-grid to the national grid. In countries where the national grid may provide users with only a few hours of electricity a day and often suffers from blackouts, rural communities served by a hybrid mini-grid conceivably could receive with more reliable service than their fellow urban consumers.

The CSIR has many years of experience and field experience in the field of hybrid mini-grid systems. Fig. 3 shows a wind/PV based hybrid min-grid system at Lucingweni village on the Wild Coast of the Eastern Cape Province.

Fig. 3 Mini-grid system, Lucingweni, E Cape Province

However, hybrid energy systems are based on exploiting site-specific resources, such as wind solar, hydro, biomass, waste and integrating these resources with storage and a control system the hybrid system would need to be optimized in terms of size and cost.

Nevertheless the electricity ratings of commonly available appliances and other equipment such as lighting systems are readily available including the electricity rating of the medical equipment that are expected to be found in rural clinics.

Table I shows the calculated electricity consumption for a model basic clinic.

Table I: Electricity consumption for a basic clinic

Qty	Item / Appliance Description	Power Watts	Avg. operating h/week	Watt-h per week
4	Lights (external) 10 h/day	40	70	11 200
22	Lights (internal)	20	40	17 600
1	TV 67 cm	80	40	3 200
1	Radio / Hi-Fi	30	30	900
1	Alarm System (48 h over weekend, 10 h/day weekday)	30	98	2 940
1	Fridge medium, modern energy efficient. 1700-2500 watt-h/day. Depends on ambient temp, thermostat setting, door openings, content turnover. Select 2 200 watt-h/day	2 200	10	22 000
1	Microwave medium (1 h/day)	1 200	5	6 000
1	Toaster 2 h/day	800	10	8 000
2	Computer (desktop) 35 cm screen	175	40	14 000
1	Printer (Dot matrix) 1 h/day	150	5	750
1	Kettle 2 h/day - high power, use must be limited	1 500	10	15 000
5	Medical appliances	100	20	10 000
1	Vacuum cleaner	800	5	4 000
1	other - switchboard small	50	40	2 000
2	other - cell phone charger	100	20	4 000
1	other - DSTV	40	40	1 600
1	other - pump 5 h/day	400	25	10 000
1	other - contingency 0.5 h/day	1 200	3.5	4 200
1	other - contingency 0.25 h/day	800	1.75	1 400
	Total watt-hours per week			**138 790**

Consequently, the estimated average power consumption of the clinic is 139 kWh/week, i.e. an electricity generation system that is sized to produce 140 kWh/week or 20 kWh/day is required.

To determine the viability and life cycle costs of a novel rural clinic the CSIR have identified two sites where monitoring and evaluation of this novel clinic could takes place.

One site is on the CSIR campus in Pretoria and the other site on the East London Industrial Development Zone (IDZ).

The CSIR Pretoria site is characterized by being a wind poor but solar rich site. The East London IDZ site is characterized by being a wind & solar rich site.

For the CSIR site, where it was assumed that the test clinic would only make use of solar radiation incident onto a small array of PV panels it was estimated that a PV array with a total area of 48 m^2 would be sufficient to power the clinic. It was further estimated that the cost of a PV based system for the CSIR site would cost approximately R280,000 exclusive of VAT.

Eveready Diversified Products from Port Elizabeth and who manufacture the Kestrel range of small wind turbines were approached to provide a quote and sizing for a wind and PV based system for the CSIR Pretoria site and the East London IDZ site. This was done to obtain a cost and correct sizing as a reference point for a PV and wind based energy systems for the clinics at these two sites.

Kestrel quoted for a 24 hour battery backup 12 volt deep cycle lead acid batteries but this can be extended to any autonomy necessary. If 20 kWhrs/day is not exceeded this should not be necessary.

Cost of Energy System for Pretoria site

For CSIR Pretoria site Eveready Diversified Products provided a quote for a fully PV based system for R291 714 inclusive of VAT

Cost of Energy System for East London site

For the East London IDZ site, Eveready Diversified Products provided a quote for a fully wind based system for R287 855 inclusive of VAT and that requires 2 x 3 000 W wind turbines.

Assessment of the information obtained indicates that a wind system is slightly cheaper than a PV only system, but is site dependent on the availability of wind and solar resources.

In the short term, the following three options are recommended for the clinic to function off-grid:

- Photovoltaic (PV) based system for the generation of electricity for sunny but wind free sites such as CSIR Pretoria campus.
- Wind based system for the generation of electricity for windy sites such as the East London Industrial Development Zone.
- Liquid Petroleum Gas (LPG) for heating and cooking.

4.5 Heating and Cooling

Heating (water and space) and cooling (space) are two requirements that are energy consumers. Bioclimatic data indicates that space cooling should not be required, but that space heating will be required. South Africa has some of the highest solar radiation levels in the world, which supports the use of solar water heaters to supply the hot water.

Typically, solar water heaters in South Africa are equipped with a back-up electrical element that is controlled through a timer and thermostat to provide auxiliary heating during days with limited solar radiation or when all hot water has been consumed.

In the situation of the rural clinic, it is suggested with the objective to minimise energy consumption, it is proposed to install a thermo syphon system *without* back up element.

The demand for hot water in the building is limited as there is no shower or bathing amenities provided. Hot water will only be required in the kitchen and bathrooms for hand and equipment washing purposes.

The final hot water demand can be calculated once the full operational requirements are known.

5 DISCUSSION

The research work that was done upon which this paper is based on has developed the basis for a generic basic clinic for the rural application in South Africa. The conceptual design is modular based and could be constructed using either conventional building technologies (brick and mortar) or Innovative Building Technologies (IBTs). The conceptual design also allows for additional functions to be added as and when required. The conceptual design of the clinic is therefore both flexible (the modularity allows rooms to be used for different functions should the requirements and needs change) and adaptable (may be extended in a number of ways).

The preliminary research finds that it is highly likely that the clinic may function off-grid under many circumstances. These circumstances relate to climatic conditions, topography of the site, location of the site, ground conditions, and the extent of the site.

It is recommended that the conceptual design be adopted as the basis of an integrated research project that also includes monitoring and evaluation. It is further recommended that the conceptual design be further developed into full sketch plans, and once the geographical location of the proposed site has been confirmed, construction documentation can be prepared.

Subject to confirmation of the intended site for the erection of the generic basic clinic as discussed in this paper, further research will be required to identify and optimize the most appropriate Innovative Building Technology system, and off-grid service technologies, such as the provision of water , sanitation, electricity, heating and cooling.

REFERENCES

[1] *Small Clinic, Brief Operational Narrative Framework,* KwaZulu-Natal Health, 22August 2012, Draft 1-Version 1.

[2] *Design Guidelines for Health Facilities, Standardized Room Data Sheets,* Western Cape Provincial Government, Department of Transport and Public Works, Directorate: Works Health.

[3] *Re-engineering Primary Health Care in South Africa, Discussion document,* Department of Health, November 2010.

[4] L. van Wyk, P. de Jager, E. Fleming, L. Duncker and S. Szewczuk, *Clinic Infrastructure: Future Clinic Design,* March 2013, CSIR internal report.

[5] S. Szewczuk, *Agrément IBT Active Certificates Categorization*, March 2014, CSIR internal report.

[6] S. Szewczuk, D. Conradie, *Evaluation of Four Building Energy Analysis Computer Programs against ASHRAE Standard 140-2007,* International Conference on the Industrial and Commercial Use of Energy, Cape Town, 2014.

[7] H. Krishna, *An overview of rainwater harvesting systems and guidelines in the United States,* Proceedings of the First Rainwater Harvesting Conference, 2003, Austin, Texas.

Principal Author: Stefan Szewczuk holds an MSc degree in Mechanical Engineering from the University of the Witwatersrand and an MBA from Herriot-Watt University He is a Senior Engineer at the CSIR and has worked on a wide range of projects around the world on behalf of the World Bank, UNDP, GEF and the EU. Stefan’s interests are in wind, distributed generation, strategy development & energy efficiency