Energy performance and Dynamic Modelling of Existing Building Infrastructure and Services in South African Universities

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ABSTRACT

This paper conceptually analyses the influence that various interdependent control parameters have on the performance of energy in the Educational buildings at Central University of Technology through the system dynamic principles; and their implication in the design of new buildings in terms of energy efficiency. For this purpose, the literature concerning building energy performance was explored prior to the analysis of a case study. The case study examined how energy efficient design solutions can lead to improved building energy usage through appropriate building orientation and form, appropriate thermal mass and insulation, improved efficiencies of electrical and lighting devices, improved natural lighting, and alternative energy systems. The analysis considers building infrastructure and services within the context of regional conditions and Green Building principles. The results indicate that by improving designs using green building principles with the aid of systems dynamics simulations, substantial improvement in energy use is achievable. It was also observed that the findings of the study can assist in the development of performance based policy for the design of new construction or retrofitting of the building infrastructure and services of the South African universities.

Key words: Energy efficiency, Green Building, High performance, Sustainability, Systems thinking,

1. INTRODUCTION

Universities are centers of learning and research. The research conducted in these institutions leads to the development of new knowledge which is vital for sustainable development of human habitations. New knowledge leads to new opportunities; therefore continuous output from research is a significant contribution universities make towards sustainable development. However, the research can be strengthened by applied action by these institutions. Cortese (2003) noted that higher education has the unique academic freedom and the sheer exposure to critical thinking to comment on society and its challenges, and to engage in bold experimentation in environmental sustainability. In many university campuses in North America and Europe, implementing Green Building (GB) practices has resulted in conservation of energy and water, reduced operating costs, and added educational benefits. The greening of campus day-to-day operations has been cited as the most successful aspect addressed by higher education institutions (McIntosh *et al*., 2008).

Most universities are located in cities; they are educational neighborhoods that influence society and policy makers, within their surroundings. Universities constitute of significantly large infrastructure and have relatively significant environmental foot prints. The question is can university infrastructure be re-engineered to become forces of good rather than detrimental to the environments which they are part of?

In this regards the cities as Forces Good Network (CFG) asks how city infrastructure can be re-engineered to enable the city to act as a force for good, to compensate deliberately and positively for the ills of the rest of man's interventions in nature (Beck, 2011). Universities being subsets of the city can lead in these efforts by research and applied action, they can become examples to cities by reengineering their infrastructure to become forces of good within the city or (cfg's). University infrastructure includes buildings and services of which energy use is important especially in the context of climate change. Therefore the objective of the paper is to explore how appropriate building orientation and form, appropriate thermal mass and insulation, improved efficiencies of electrical and lighting devices, improved natural lighting, and alternative energy systems can lead to energy efficient solutions with improved building energy usage in the buildings of the universities of South Africa. In addition the purpose of this study is to demonstrate how systems thinking and systems dynamics modeling principles can be used to create conceptual models to facilitate the analyses of relationships of parameters that affect energy consumption in the building.

In this respect the analysis followed a case study approach followed by conceptual modeling .This study reviews the main strategies for reducing energy use in new and existing buildings in South African universities, a case study of 4 buildings are presented in which systems thinking is used in analyses of the buildings. A conceptual systems dynamic model is simulated to depict the interrelationships of various elements to present the best possible option for energy efficiency in the buildings.

2. RELATED LITERATURE

Reduction of energy use in university buildings

In the development of building design, it has been a normal practice for the designers to focus on the building shape and appearance without considering energy and resource consumption. In this method of design, development models are created that depict the geometric representation of buildings but do not give an overall understanding of how the design model performs with regards to building aspects that include, efficiency in energy (EE), (Geyer 2011).

According to Allen & Witzerland, energy demand is met by energy consumption, which in turn causes GHG emissions (Allen & Witzerland 2012.) Therefore a reduction in energy consumption in buildings is vital to improve energy efficiency and reduce GHG gases in the environment and to achieve savings in usage of energy.

From the modeling point of view it is possible to analyze urban subsystems separately or analyze the system as a whole (Allen & Witzerland 2012.). University buildings and infrastructure are subsystems of the urban environment, and their designs can be considered as complex systems with many subsystems and comprising of elements that are interdependent. These inter-dependent parameters can be established, analyzed and measured from the system by using dynamic models. This view is supported by Greyer who noted that to achieve significant improvement in the design, the key is the use of appropriate building modelling methods. This concept can be related to the systems concept which is well corroborated by Forrester (1969) and Sterman (2000), which entails that in systems thinking the world can be regarded as a complex system to understand how everything is connected to everything else

Building parameters & interdependent relationships of energy efficiency in sustainable design

Building shape and geometry

Parasonis, Keizikas & Kalibatiene (2012) in their work 'Possibilities to Reduce the Energy Demand for Multi-storey Residential Buildings' found that changes in the shape of the building cause changes in energy losses, although physical characteristics of the building remained the same. In volumetric design of buildings, it is important to rely on the use of architectural solutions providing for their higher energy efficiency and lower consumption of other resources. (Parasonis, Keizikas, and Kalibatiene 2012).

Building Orientation

Appropriate Building orientation is necessary to a maximise strategies for natural heating/cooling ventilation and lighting in building design. Orientation influences ventilation and access to natural light. These strategies include proper window placement (also doors as they comprise a large part of the exterior building envelope and have a major impact on the human activities inside the building and on energy use) and day lighting design, selection of appropriate glazing for windows and skylights, proper shading of glass when heat gains are not desired, use of light-coloured materials for the building envelope and roof. By integrating these principles into building design, demand for energy may be reduced significantly, (Lun, and Ohba, 2012). Haase & Amato (2009) noted that in many climates the optimum orientation would be a north-south orientation with the long facade facing towards the equator minimizing the facade areas facing east and west. (Haase & Amato 2009)

Openings

Fenestrations play vital roles in providing thermal comfort and optimum illumination levels in a building. They are also important from an architectural standpoint in adding aesthetics to the building design. In recent years, there have been significant advances in glazing technologies. These technologies include solar control glasses, insulating glass units, low emissivity (low-e) coatings, evacuated glazings, aerogels and gas cavity fills along with improvements in frame and spacer designs.(Sadineni, Madala & Boehm, 2011).

Smart control technologies

Depending on orientation and location the control of electrical power with regards to day light leads to savings of 45%–60% in office buildings(Roisin et al. 2008). Garg and Bansal also noted that smart Energy occupancy sensors installed in buildings can save up to 35% energy consumption in buildings (Garg & Bansal 2000).

Other important parameters in analyses of buildings include thermal comfort, daylight and natural ventilation; these are interdependent on building orientation, size and function. Improvements in these parameters significantly improve the performance of buildings which indirectly reduces energy consumption and greenhouse gas emission. Harvey (2009) summarizes the steps in the most basic Integrated Design Process (IDP) to the following:

- to consider building orientation, form, and thermal mass,
- to specify a high-performance building envelope to maximize passive heating, cooling, ventilation and day lighting,
- to install efficient systems to meet remaining loads,
- to ensure that individual energy-using devices are as efficient as possible and properly sized,
- to ensure the systems and devices are properly commissioned,

However, Harvey also indicated that on focusing on building form and a high-performance envelope, heating and cooling loads are minimized, day lighting opportunities are maximized, and mechanical systems can be greatly downsized (Harvey 2009). All of these results in reduction of energy input within the system and more efficient use of energy

Additionally the Green Building Council of South Africa (GBCSA) recommends the use of the following

- Increase sub-metering this is the installation of meters in different floors or departments in the building to monitor energy consumption. This allows facility managers to fine tune operational procedures to minimize energy consumption.

- Design of artificial lighting with minimum energy consumption (through proper spacing)
- Use of daylight sensors maximize daylight use
- Use of motion sensors to encourage use of lighting only in occupied areas

Summary findings of the literature review

The review of literature reveals that the multidisciplinary interdependencies in the design of buildings caused by the demand for energy efficiency and sustainability require a holistic approach in which all interdependent parameters require evaluation in order to improve building performance; this study therefore seeks to use SD approach to achieve this.

3. METHODOLOGY

The methodology used in this study follows the assessment (empirical study) of buildings based on green building rating tools, case study analyses and system dynamic models (development conceptual causal feedback loop mechanism and computational model) to map the interrelationship among the parameters to achieve high energy performance in the buildings of the universities.

Assessment of building parameters for performance using green building rating tools

A green building is also known as a sustainable or high performance building. Goals of green buildings include site structure design efficiency, energy efficiency, water efficiency, materials efficiency, enhancement of indoor environmental quality, operations and maintenance optimization and waste reduction (GBCSA, 2008), After the building is built, the product is expected to operate and perform in a way that meets the required goals.
The measurement of these efficiencies and aspects are generally done by using Green Building (GB) tools, which include the United States Green Building Council's Leadership in Energy and Environmental Design (LEED); Britain's Building Research Establishment Environmental Assessment Method (BREEAM); and the Green Star Rating System used in Australia and South Africa. These rating systems form the assessment tools, which show if a building is actually 'Green' or what category of efficiency in various criteria the building has attained. Most rating systems, if not all, deal in one way or another with site selection criteria, the efficient use of energy and water resources during building operations, waste management during construction and operations, indoor environmental quality, demands for transportation services, and the selection of environmentally preferable materials while doing an admirable job of fostering and facilitating integrated design practices holistically (Trusty & Scott, 2003). The various categories assessed by these rating tools are made of elements and components that have interdependencies and require multidisciplinary approaches in the design of the high performance sustainable building.

Green star rating tools

In both LEED, and Green Star building assessment system a building's sustainability criteria can be rated based on its score. Both rating tools are regulated by a points system, which determines a building's certification level according to the number of points earned. There are a total of 9 categories and they are divided into credits, each of which addresses an initiative that improves or has the potential to improve a design, project or buildings' environmental performance. Points are awarded in each credit for actions that demonstrate that the project has met the overall objectives of Green star SA and the specific aims of the Green star SA rating tool (GBCSA, 2008). The green Star rating tool will be used in this study to measure the performance of elements that influence energy consumption. It forms part of the analyses and will complement the use of SD models. Energy efficiency can be affected by types of building materials used in the building, increasing use of daylight use of motion occupancy sensors etc. The effects of these elements on building performance can be measured using rating tools, however the SD models further analyses the interdependencies of these elements with each other and analyses how they operate as subsystems and systems. This will aid us in determining how these elements can be combined

System Thinking and system dynamic modelling and its justification in the Green building design

A system constitutes a set of components, which are interlinked and interdependent on each other to perform a function as a whole (Von Bertalanffy, 1974; Forrester 1968). In a system, if a subsystem performs at a higher efficiency than others or becomes defunct then the effect is felt on the whole system. As a result, the whole system may perform at lesser efficiency or even may become paralyzed. In order for the system to perform at a higher efficiency all the subsystems of the system are to work in a coordinated manner.

According to Keeler and Burke (2013) green buildings require an integrated approach to design because every design decision produces a cascade of multiple effects rather than an isolated impact. Successful integrated design requires a necessary understanding of the interrelationship of each material, buildings system, and the space requirements of buildings. It requires all players to think holistically about the project rather than focus solely on individual part (Keeler & Burke 2013). Geyer (2012) noted that for sustainable design, often called green building design, one must provide a holistic model because of the relevant criteria crossing disciplinary borders interdependencies. Green buildings require an interdisciplinary approach which needs to analyze interdependencies of engineering and geometric considerations. Greyer further argues that multidisciplinary optimization requires a mathematical or algorithmic formal definition of the interdisciplinary interdependencies. Energy efficiency is a significant consideration in design of green buildings.

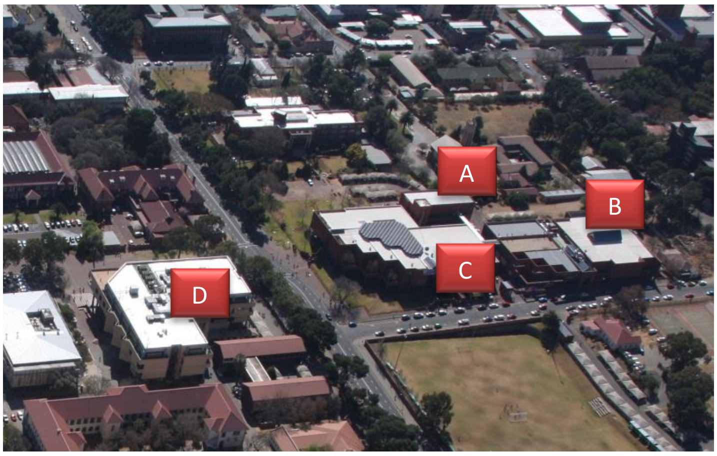
In this particular investigation a conceptual causal feedback relationships (model) followed by development of SD model over and above the results of the statistical analyses were resorted to. A conceptual causal feedback relationships (model)is a consistent and unifying theory of behaviour taken from bits of information about the real world (Wolstenholme, 1992 and Robinson, 2008). The rigorous structural framework provided by SD assists in eliciting and displaying information used to build a conceptual model (Forrester, 1994; Lane and Oliva, 1998), which allows to understand how and why the dynamics of concern are generated and enable policy and strategic interventions based on causal feedback relations to improve the situation (Forrester, 1968, 1969) Lee, Choi and Park, 2005, Montibeller and Belton, 2006).

4. CASE STUDY

The case study assessment was focused on the 3 buildings from Faculty of Engineering and Information and the university library at the Central University of Technology Free-State, South Africa (Fig 1). The scope of this study is limited to assessment of nonresidential education buildings. 4 different non-residential functional buildings, indicated in plans (B,C,D) are used from academic/ instructional functions while building A building is used for administrative purposes (Engineering Office building building).These have been analysed as a case study in this study. The focus of assessment is energy efficiency and to compare performance of the buildings with respect to the standards expected of high performance green buildings using the Green star SA rating system. In this respects the objectives of this case study are to (1) assess the energy efficiency in existing buildings in South African universities based on green building principles, (2) Evaluate the performance of building materials used in the existing buildings with respect to energy efficiency and indoor quality, and consequently (3) establish conceptual systems models for improving energy efficiency, in the assessed buildings.

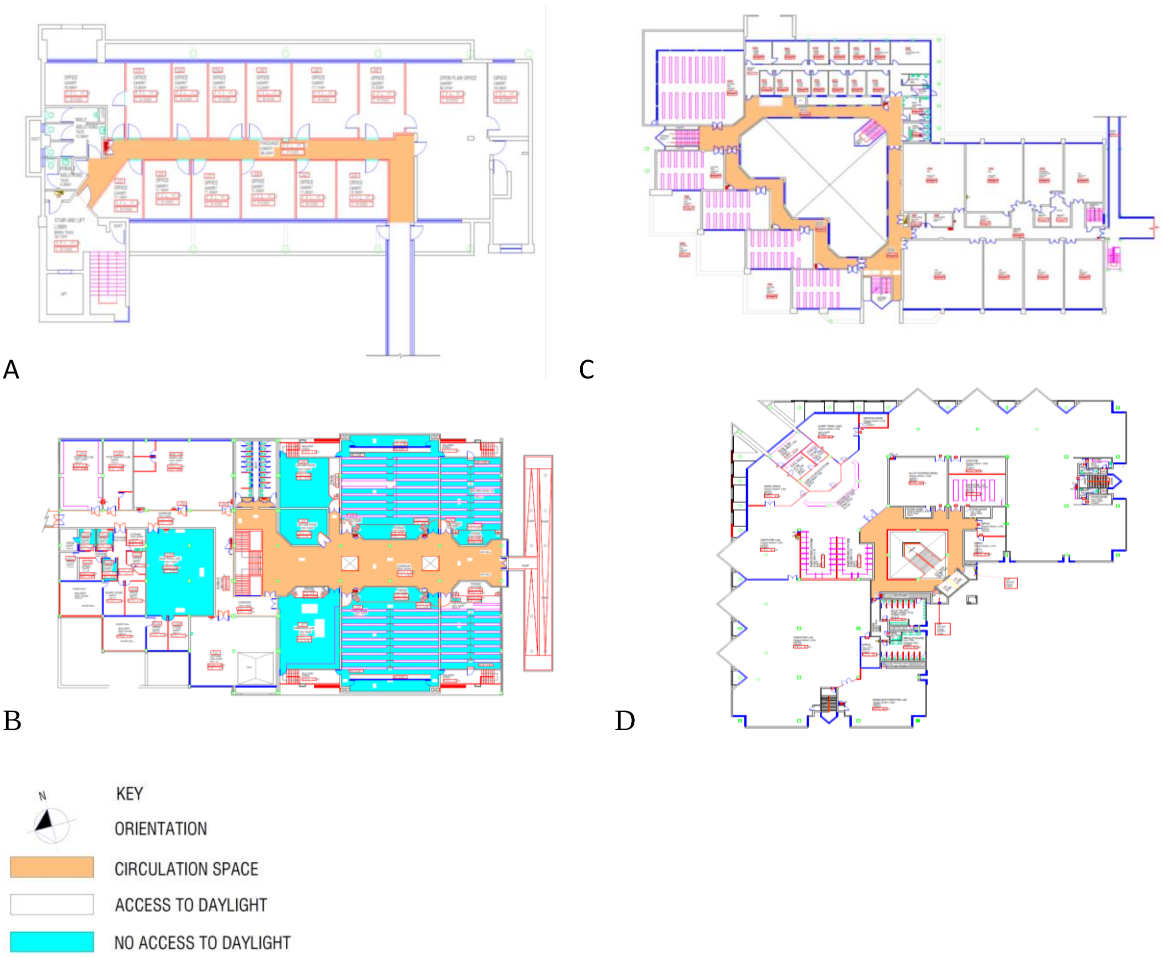
The assessments were conducted by awarding credit points in a scale from 1 star to 6 stars to various elements and performances of the buildings based on the Green Star rating system adopted in South Africa.

Fig 1 Arial photo of Buildings at Central University of Technology



A. Engineering Office Block, B. BHP 1, C. BHP2, D. Library

Fig 2 Typical floor plans of assessed buildings



Building A functions mainly as an administrative building and uses mechanical ventilation systems for heating cooling and ventilation. The offices have access to daylight and use both artificial and natural means for lighting.
Building B functions primarily as a lecture block, it depends on mechanical means for ventilation and lecture rooms depend only on artificial lighting, because there are no windows.
Buildings C and D are 3 storeys and consists of large Atriums located at their centres. In Building C lecture the rooms have large windows which remain closed for most of the year that gives access to daylight but limited ventilation since there are limited openings on the internal walls of the lecture rooms. The Lecture rooms in Building C use a combination of daylight and artificial light. In the one sided corridor configuration, the opposite side of the corridors have large windows which provide sufficient daylight from the atrium to the corridors but not to the classrooms, because adjacent walls between classrooms and corridors do not have minimum glazing or openings. A portion of the building has a two sided corridor with staff offices on either side of the internal walls, which do not have sufficient access to natural lighting, and these spaces are served by electrical lighting, and mechanical ventilation.
Building D differs from C in terms of function however both have access to natural light however the orientation of building D and the larger sizes of windows allows for more natural light. Both buildings C and D also have a large central atrium with transparent roofing, which lights up the entrance lobby.
The east and west wings constitute two sided corridors which have access to natural light from the nearby atrium. The offices in these buildings are equipped with mechanical ventilation systems.

Assessment of energy efficiency

Table 1 presents the assessed relationships among the various parameters with regards to the state of energy efficiency in the buildings**.** In cases C, & D proper orientation and use of atriums result in reduction in the energy consumption through balancing feedback loops. However, specifically the building B has a less complex geometric configuration and maximises the north south orientation, which affords the building greater access to natural light. Further, in case of building C & D windows located on the East and West elevations (facing), do not utilizes shading devices, which helps to prevent glares because of excessive day light access.

Building A is oriented in such a way that the longest side faces the north. This orientation results in more access to daylight, which helps in the reduction in the use of artificial means of lighting and consequently decrease in energy consumption as a positive feedback.
With regards to the functions of the buildings, A is mainly administrative and uses relatively smaller volumes of space and uses mechanical ventilation system. In contrast buildings C & D which is used for teaching and learning purposes have large volumes of space. The large volume of space enables easier air flow in the building, which assists in natural ventilation. Thus, it is observed that the mechanical ventilation system in the building B develops a positive feedback relationship with the energy consumption resulting into higher energy consumption. However, on the other hand the natural ventilation system in the buildings C & D creates a negative feedback relationship with the energy consumption, thereby reducing

energy consumption. Therefore, while a small volume space with mechanical ventilation develops a positive feedback relationship with energy consumption, a large volume of space with natural ventilation system develops a negative relationship with energy consumption.
There is a major contrast in building B with A,C & D. Building B maximizes orientation (north-south), it does not have windows in the majority of lecturing rooms. This means a complete dependency on artificial lighting and mechanical means for ventilation in order to satisfy minimum standards.

In the Green star SA rating tool the maximum points available for energy efficiency is 30. However the case study revealed that both the buildings fall short of Green star rating. The building 2(a) and scores a meagre 13 and building 2(b) scores 4 out of maximum available 30 because of the non-availability of appropriate low emission ventilating equipment and use of artificial lighting (Table 1). However, the building 2(a) scores higher than the building 2(b) because of the availability of natural lighting facilities and more use

Table 1: Assessed interdependent parameters for Energy efficiency:

Engineering Building Parameters : relative to Green Star SA parameters	Effects of Windows/No windows		Effects of Orientation		Energy Consumption		Compliance with Green Star SA Parameters		Green Star SA Credits	
Buildings assessed	**A, C & D**	**B**	**A, C & D**	**B**	**A, C& D**	**B**	**A,C & D**	**B**	**A,C & D**	**B**
Daylight Access: longest side of the building faces North for A, C & D Atrium in both C & D	- Daylight	+ Artificial Light	- Daylight	+ Artificial Light	- Decrease	+ Decrease	✓	×	3	0
Daylight Access: C & D Most windows facing east & west with no shading devices A: all windows on North-South axis	- Daylight :D Larger windows	+ No Daylight	- Daylight A : best orientation	+ No Daylight	- Decrease	+ Increase	×	✓		
Building Function : C & D Large volumes of functional areas using natural ventilation A: Limited volumes of functional areas using mechanical ventilation. B: Large volumes of functional areas using mechanical ventilation	C &D- Ventilation (natural) A+ Ventilation (Mechanical)	+ Ventilation (Mechanical)	_ Ventilation	+ Ventilation	C & D -Decrease A +Increase	+ Increase	C&D ✓ A ×	×	C&D: 10 A: 0	0
Daylight Sensor : Not available in A,B, C & D	+ Daylight	+ Daylight	+ Daylight	+ Daylight	+ Increase	+ Increase	×	×	×	×
Motion Occupancy sensor : Not available in A,B, C & D	+ Increase	+ Increase	+ Increase	+ Increase	+ Increase	+ Increase	×	×	×	×
Energy efficient Mechanical systems / appliances: not available in A,B, C & D	+ Ventilation	+ Ventilation	+ Ventilation	+ Ventilation	+ Increase	+ Increase	×	×	×	×
							Total		13/30	0/30

Establishment of conceptual systems models to improve Green building attributes in the buildings of the case study: Opportunities

A comprehensive use of Green star parameters is addressed in the analyses of how these buildings can be modelled to improve energy efficiency in the buildings. The results and recommendations are indicated in Table 2.

Table 2: Design strategies to aide in improving Energy Efficiency

Green Star SA Credt	Credit Description	Goals	Green Star SA Credit Points	Case Study Recommendations	Effects of Function of Building*		Energy Consumption *
					A, C & D	B	A, B, C & D
Ene-1	Green House Gas Emissions (Credit uses ASHREA's Advanced Energy Guide For small office Buildings; Summarized here in the Goals and case study recommendations).	Reduce internal loads	20	Use of efficient equipment Lighting /appliances	- Effect		- (reduced)
		Reduce heat gain/ loss through building envelope		Control Solar gain Increase Insulation Reduce heat & gain loss from infiltration	- Effect		- (reduced)
		Reduce thermal Loads & Refine building to suit local conditions		Utilize passive solar Design:	- Effect		- (reduced)
		Use more efficient SWH systems		Select efficient water heating equipment Minimize pipe distribution	- Effect		- (reduced)
Ene-2	Energy Sub-metering	Required for management of energy usage	2	Increase sub-metering	- Effect		- (reduced)
Ene-3	Lighting Power Density	Design for artificial lighting with minimal energy consumption	4	Correct spacing of Lighting.	- Effect		- (reduced)
Ene-4	Lighting Zoning	Design for greater flexibility for light switching to encourage lighting only occupied areas	2	Motion occupancy Sensors Daylight sensors	- Effect		- (reduced)
Ene-5	Peak Energy Demand	Reduction of peak demand on energy supply	2	Distributed Energy systems	- Effect		- (reduced)

Note: ***(**+/- refers to an increase / decrease in energy consumption)

5. CAUSAL FEEDBACK RELATIONSHIPS AMONG THE CONTROL VARIABLES INFLUENCING ENERGY EFFICIENCY SD MODELLING

It is significant to note that the effect of changing the building form and adding fenestrations would have a profound effect on the model. As seen from the investigation, the existing building form of building A & B, which consists of a simple rectangular shape would mean greater access to access to daylight, however smaller fenestrations or no fenestrations would eliminate this advantage greatly reduce this advantage. So, several simulations of rectangular or less complex forms with appropriate orientation, adequacy and location of openings can improve the energy efficiency through proper use of day light and natural ventilation leading to reduction of energy consumption. There are also other consequences in adopting a simpler form such as the effect of building form on the function of space. The results indicate that adopting the form of a simpler rectangular shape with longitudinal axis facing north improves indoor environmental quality (IEQ) substantially which improves energy consumption. This case study has proved that orientation and building form which effect indoor air quality (IAQ) are very significant parameters in building design which leads to several consequences and needs to be carefully considered.

The figure 3 presents the conceptual causal loop relationships among the various parameters involved in achieving energy efficiency in a building**.** It is indicated that energy consumption is affected by indoor quality and building use, thus energy consumption will increase depending on functions of the buildings as shown in the causal feedback loop B1. The building orientation and use of natural lights also affect energy consumption depending on functions as shown in causal feedback loop R1. These two main prominent parameters are featured clearly in the cause and use tree diagram as shown in figure 4(a) and 4 (b), which have direct impacts on energy consumption. Further, energy consumption also influenced by the building geometry, which is a function of shape and size of the building. It is apparent that the shape and size of the building is decided based on the use of the building apart from its architecture value. Thus, building geometry, building use and energy consumption is interconnected by a feedback mechanism as shown in loop R2. Therefore energy consumption in building is reinforced by two causal feedback mechanisms R1 and R2 and balanced by the causal feedback mechanism B1. Further openings in a building are related to its shape and size and orientation and influence the requirement of lighting (artificial lighting) and ventilation (air-conditioning), which in turn influences indoor quality of the buildings. Besides, indoor quality is also affected by the building materials used in the various elements such as roofs, floors, walls and openings. Thus, there is a clear inter-linkage with the various parameters of a building such as orientation, building use, geometry and indoor quality with the energy consumption of a building in specific and interlinked feedback mechanisms as shown in the cause and use tree diagrams (Fig 4(a) and (b)).

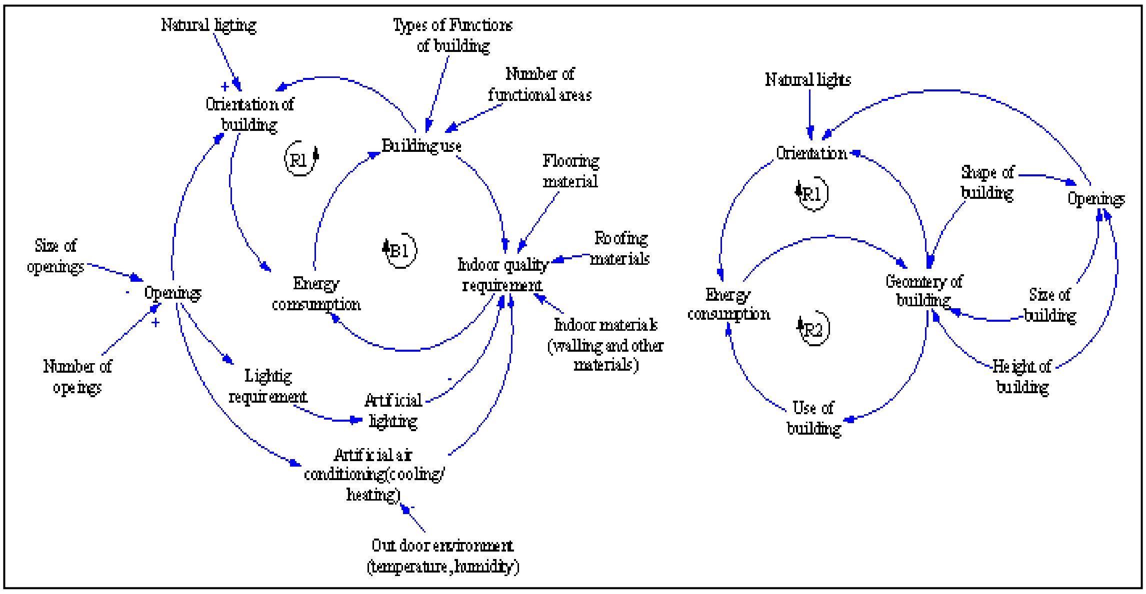


Fig 3 Causal feedback loop diagrams for energy efficiency in buildings

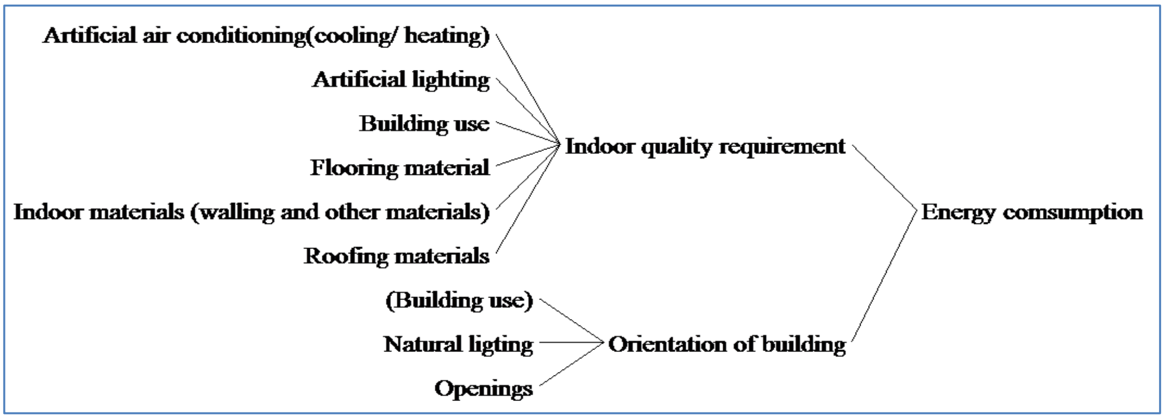


Fig 4(a) Cause tree for energy consumption and consequent efficiency

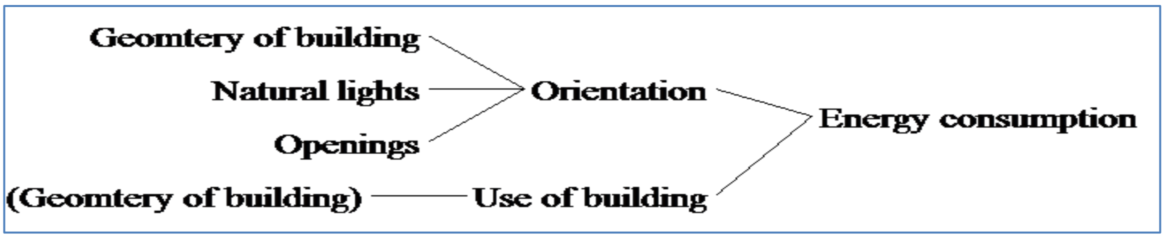


Fig 4(b) Use tree for energy consumption and consequent efficiency System dynamic modelling

A system dynamic model has been developed based on the causal feedback relationships among the various control parameters as discussed above. Figure 5 presents the stock structure or flow diagram of the SD model developed to assess the energy consumption in a building.

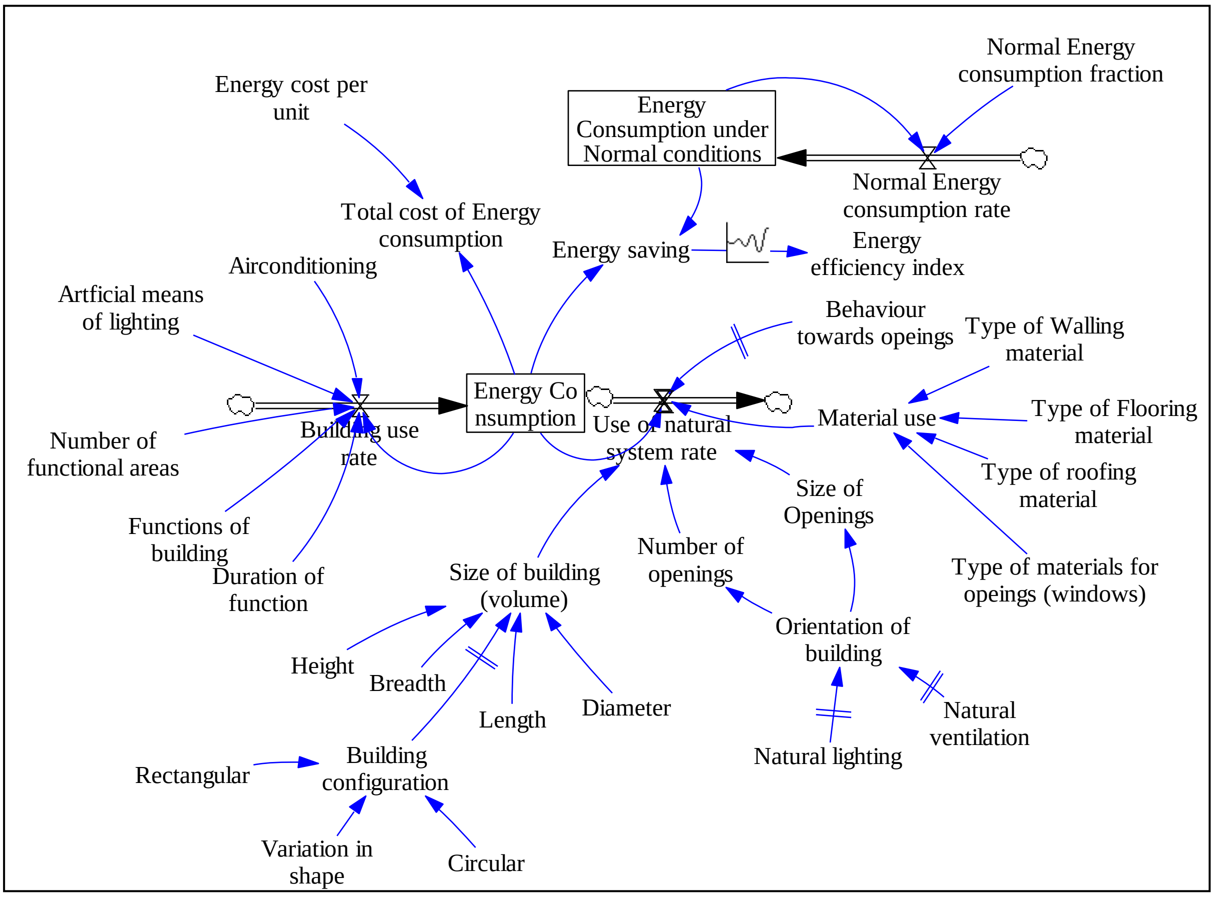


Fig 5. System dynamic model (proposed stock flow diagram) assessing energy consumption in buildings. Please note this is only a proposed diagram there is still on-going data collection.

Table 3 shows the various variables such as stocks, rates, auxiliaries and constants used in building the model.

Table 3. Variables used in model development

Stocks	Rates	Auxiliaries	Constants/Fractions
Energy consumption under interventions (E)	Building use rate (BR)	Building configuration (BC)	Functions of building (BF)
Energy consumption under normal conditions (Enc)	Natural system use rate (NR)	Material use (MU)	Number of functional areas (FA)
	Normal energy use rate (NCR)	Number of openings (NO)	Duration of function (DB)
		Orientation of building	Artificial lighting (AL)
		Size of building (SB)	Air conditions (AC)

	Size of openings (SO)	Computing/ lab functions (CLF)
	Energy saving (ES)	Flooring material (FM)
	Energy saving index (ESI)	Walling material (WM)
		Roofing material (RM)
		Materials for openings (MO)
		Natural ventilation (NV)
		Natural lighting (NL)
		Rectangular shape
		Circular shape
		Variation in shape
		Height (H)
		Breadth (B)
		Length (L)
		Diameter (D)

These equations represent the mathematical expressions of interdependent relationships in the model. There are two stocks in the model such as energy consumption under normal conditions and Energy consumption under policy interventions. The energy consumption under interventions is characterised by three feedback mechanisms (R1, R2 and B1) as discussed earlier. Based on the causal feedback relations it is envisaged that energy consumption will increase by the use of artificial lighting, use of air conditioning, increased function of the buildings, higher number of functional areas, higher duration of use of buildings**.** However, on the other hand energy consumption will be reduced by using natural systems. The natural systems use rate is influenced by the number of openings (influenced by appropriate orientation, natural lighting and natural ventilation), size of the building, material use and behaviour towards opening by the users of the building. Thus, Energy consumption under interventions is balanced by both building use rate and natural system use rate. However, the energy consumption under normal conditions is a simple function of the normal energy consumption rate of the building based on its normal functions and other parameters such as number of functions areas, duration of function and use of artificial means of lighting and air-conditioning. Therefore the saving in energy or energy efficiency is a function of difference between the energy consumption under interventions and energy consumption under normal circumstances.

Mathematically the stock variables are presented by equation 1 and equation 2. Equation 3 presents the energy efficiency in the building.

Energy consumption under interventions

$$E = E_i + E_i \int_{t0}^{t} (BR - NR)dt \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Energy consumption under normal conditions is

$$Enc = E_{ni} + \int_{t0}^{t} E_{ni}(NCR)dt \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Energy savings or Energy efficiency is

$$ES = [\frac{E_{nc} - E}{E_{nc}}] * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

The rate variable used in the model such building use rate and natural system use arte is given by equation 4 and 5.

$$BR= \sum_{ij}(wi * BRFj)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

$$NR=\sum_{ij}(mi * NRFj)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (5)$$

Where, BRF and NRF are the various auxiliary variables and fractions used in the development of the rate variables. The w_i and m_i are the weightages assigned to the variable based on their influence, which are derived from case study analyses, empirical studies and expert opinion.

The detailed equations used to develop other various auxiliary variables are presented in the appendix.

Further research work

The data collection process is under progress and once the data is available the model will be simulated for preliminary results to understand its behaviours with respect to the real system, then will be calibrated, trained and validated before applying to develop make scenario analyses and optimise the energy efficiency in a building leading to development of green buildings, which would act as a catalyst for campuses as forces good under the larger paradigm of CFG. The systems model will be used to determine the most appropriate calibration to maximise the reduction of energy use in the buildings. Reduction of energy consumption will reduce the dependence of the buildings on the University's energy resources. The combination of reduction of energy use with adoption of other performance features (including efficient usage of water resources) could aid the university to become a force for good in the city of Bloemfontein

6. Conclusion

The objectives of the study were to assess the energy usage efficiency in existing buildings in South African universities based on green building principles. Therefore this study applied a systems approach and SD modelling principles to develop scenarios based on which policy interventions can be made to develop green buildings or transform existing building to green buildings. In this regard, the building parameters examined include effects of the rate of use of natural systems and the rate of use of mechanical systems. The case study revealed that building A & B satisfied the requirements for appropriate north south orientation to maximize sunlight and ventilation requirements but in building B improper placement of windows minimized the impact of natural lighting and ventilation. This is an indication that the system dynamics approach identifies these interdependencies were one element i.e., improper placement of openings (even with appropriate orientation) impacts energy efficiency of the entire system. The case study also revealed that there is a lack of control sensors for both daylight use and occupancy use. This is also significant because control of energy use with regards to function of use over a specified time period can improve energy usage because of the ability to use energy only when required. This is also important because system dynamics analyses how a system performs over a period of time. The case study results were used to derive the system dynamic model which depict how the various building elements are interdependent and influence each other. A stock and flow diagram was derived from these interdependencies and mathematical relationships were derived to further define these interdependencies. The case study results presented in this paper aims at developing design guidelines and performance options in order to improve existing building codes that are relevant for the planning and design of South African university buildings. This case study also revealed that at the current state the buildings analysed in the case study do not comply with the energy efficiency standards of Green Buildings in South Africa. However, the conceptual system dynamics models and stock and flow diagram show that by tweaking of various design parameters such as orientation, geometry of buildings, provision of appropriate openings, and use of natural lights can reduce energy consumption and consequently enhance the energy efficiency which a significant in achieving sustainability of the buildings as envisaged by a holistic approach to design.

The limitation of this study is that the research is yet to be completed and data collection is under progress. The computational model developed will be simulated once the desired data is available and used for scenario analyses for deriving policy interventions to develop Green Buildings or transforming the existing buildings to Green building in the Universities of South Africa, which is the further scope of this research.

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Appendix:

These equations below represent a more comprehensive mathematical expression of the equations in section 5, where they have been summarized.

$MU = \mathrm{x1} * \mathrm{FMF} + \mathrm{x2} * \mathrm{MOF} + \mathrm{x3} * \mathrm{RMF} + \mathrm{x4} * \mathrm{WMF}$. (*Where x refers to the weightages).*

$NO = \mathrm{z1}(\mathrm{y1} * \mathrm{NLF} + \mathrm{y2} * \mathrm{NVF})$, (*Where y refers to the weightages.)*

$SO = \mathrm{u1}(\mathrm{y1} * \mathrm{NLF} + \mathrm{y2} * \mathrm{NVF})$

$SO = \mathrm{u1}(\mathrm{y1} * \mathrm{NLF} + \mathrm{y2} * \mathrm{NVF})$

$SB = \mathrm{BC}(\mathrm{l1} * \mathrm{BF} + \mathrm{l2} * \mathrm{HF} + \mathrm{l3} * \mathrm{HF} + \mathrm{k1} * \mathrm{DF})$ *(where l refers to the weightages)*

$BC = (\mathrm{C} + \mathrm{R} + \mathrm{V})$

BR=$\sum E * (W1 * BFF + W2 * DBF + W3 * FAF + W4 * ALF + W5 * ACF + W6 * CLF)$

(*Where W refers to the weightages.)*

NR=$\sum E * (M1 * MU + M2 * NO + W3 * SB + M4 * SO + M5 * BO)$

$MU = \mathrm{x1} * \mathrm{FMF} + \mathrm{x2} * \mathrm{MOF} + \mathrm{x3} * \mathrm{RMF} + \mathrm{x4} * \mathrm{WMF}$

$NO = \mathrm{z1}(\mathrm{y1} * \mathrm{NLF} + \mathrm{y2} * \mathrm{NVF})$

$SO = \mathrm{u1}(\mathrm{y1} * \mathrm{NLF} + \mathrm{y2} * \mathrm{NVF})$

$SO = \mathrm{u1}(\mathrm{y1} * \mathrm{NLF} + \mathrm{y2} * \mathrm{NVF})$

$SB = \mathrm{BC}(\mathrm{l1} * \mathrm{BF} + \mathrm{l2} * \mathrm{HF} + \mathrm{l3} * \mathrm{HF} + \mathrm{k1} * \mathrm{DF})$

$BC = (\mathrm{C} + \mathrm{R} + \mathrm{V})$