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Potential Impact of Climate Change on Municipal Buildings in South Africa

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Abstract

Municipal buildings are an essential component of daily life. Without schools, hospitals and other public buildings, society and economy could not function. Therefore a failure to consider the potential impact of climate change on municipal buildings would be both costly and detrimental to sustainable development. In this paper the authors present research undertaken to ascertain the potential impacts of climate impacts on municipal buildings in South Africa. A two-phase approach was adopted. Firstly the appropriate climate effects on a given building inventory, in a selected location, were determined; then the cost impacts on that building (based on a set of stressor-response functions) were applied. The results of the study predict that the total impact of climate change on buildings in South Africa could vary between USD \$42.7 million average annual costs in the median scenario and USD \$214.3 million average annual costs in the maximum scenario. The results presented are all incurred costs, which need to be addressed to avoid health and safety issues. However costs would be much higher if the existing stock was augmented without considering climate change impacts. The research provides an understanding of the cost of climate change and how the maintenance and adaptation of the unsustainable buildings may divert resources from sustainable development. The results of the research may also present an opportunity for existing buildings to be retrofitted with alternative, sustainable technologies, which serve to decrease vulnerability to climate change impacts going forward.

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1. Introduction

South Africa is the largest economy in Sub-Saharan Africa and the highest regional emitter of carbon dioxide. Ranked 11th globally, South Africa is taking a leading role in reducing and mitigating climate change impacts (DFID, 2011). Earlier work by the UNFCCC, IPCC, World Bank and others, have attempted to quantify the impact of climate change on physical assets that will be affected in the coming decades. The study presented in this paper adds to this research through an examination of the potential impact of climate change on municipal (non-domestic) buildings in South Africa. The study focused on using an engineering approach to determining the specific effects of climate stressors on building systems. Schools, hospitals and public buildings were selected for evaluation because of their economic, social and development importance and because as investment buildings they are expected to have a long lifespan. The study presented in this paper examines the extent to which climate change from 54 General Circulation Model (GCM) climate scenarios, approved by the Intergovernmental Panel on Climate Change (IPCC), will divert resources from the further development of the built environment to the maintenance and adaptation of the existing buildings.

2. Methodology

2.1 Approach

In order to determine specific climate impacts, a methodology based on a stressor-response approach was adopted after Chinowsky and Arndt (2012). This methodology employs an assumption that exogenous factors (stressors) have a direct effect on focal elements in a building. In this context, the exogenous factors were incremental changes to precipitation levels, temperatures, storm frequency and wind speeds. Therefore in the analysis undertaken, a stressor-response value was the quantitative impact that a specific stressor had on a specific building element. A two-phase approach was adopted. Firstly the researchers determined what the appropriate climate effects were for a given building inventory for a selected geographical location; then the cost impacts were applied to the building, based on a set of stressor-response functions. Building stressor-response functions were defined based on the potential degradation (or other impact) that may be anticipated as a direct result of temperature or precipitation changes. As indicated above, the potential impact of climate change on buildings can be varied and extensive. The approach adopted for this study focused on potential impacts that had been detailed in existing research, as well as ones that had a mitigation path that could be accomplished through proactive adaptation:

- Exterior cladding impact;
- Roofing impact including drainage; and
- Indoor airflow impact (including the mitigation of potential building contaminants).

The overall approach for determining potential impacts involves three steps of analysis:

1. Climate model projections;
2. Existing building stock estimation; and
3. Analysis of climate change impacts on building components.

2.2 General Circulation Models (GCMs)

The climate change projections used in this study were analysed using data from GCMs. GCMs provide climatological data for future climate change scenarios up to the year 2100. The data used in this analysis included the available A2, A1B and B1 scenarios, which represented different scenarios of future development based on the accepted definitions of the Intergovernmental Panels Fourth Assessment Report (IPCC, 2007). To provide a robust analysis of possible climate change projections, all GCM data sets approved by the IPCC containing complete data projections for climate data for South Africa were used in the analysis, 54 in total. The research presented in this paper was conducted using climate change projections analysed by GCMs at the resolution of 0.5° grid squares. The GCMs selected were the models that had complete datasets appropriate for making temperature and precipitation projections up to the year 2100 (Schlosser *et al.*, 2012). For each model, historical monthly climate data was used from the Climate Research Unit (CRU) for 1951–2000 to produce a historical baseline scenario for each of South Africa's geographical regions. The baseline scenario assumed that future weather patterns would retain the characteristics of historical climate variability. Taking the baseline scenario, a 10-year moving average of the monthly deviations in temperature and precipitation were used to establish average deltas that were applied to the new projected baselines in each GCM.

2.3 Estimation of Buildings Inventory

It was necessary to use two approaches to gathering data in order to quantify current building stock in South Africa. The first was to gather actual building stock data from sources such as Ministries and NGOs that track data for building stocks in South Africa. However, these accurate counts were not always available. In this instance a methodology was required to estimate the number of buildings based upon South Africa's geography and demography. In both approaches, the building stock was divided into representative categories based upon urban and rural classifications for primary and secondary schools, public administrative buildings and hospitals. When actual data was not available, it was necessary to use an approach previously developed for a study conducted by the Asian Development Bank (Hughes and Chinowsky, 2012). Specifically, building inventory was based on population densities in given areas. Using these densities and known allocations of public buildings in similar locations in the country, allocations were made in given geographic locations as an estimate.

2.4 Impact Functions

The stressor-response methodology was based on the concept that materials and components in buildings have specific responses to external stressors such as precipitation and temperature. The stressor-response factors were developed by analysing specific material and system responses on the effects of each stressor. These effects were then applied to specific types of building systems based on the appropriate climate context. This process utilised multiple baseline data inputs. A combination of material science reports, usage studies, case studies and historic data were used for each category. Where possible, data from material manufacturers was combined with historical data to obtain an objective response function. Where data was not available, response functions were extrapolated based on performance data and case studies from sources including the Department of Human Settlement as well as the World Bank and the Asian Development Bank.

The stressor-response factors were divided into two general categories:

1. Impacts on new construction costs: focusing on the additional cost required to adapt the design and construction when rehabilitating a building to changes in climate expected to occur over the building's lifespan; and
2. Impacts on maintenance costs: increases or decreases in recurring maintenance cost that would be incurred due to anticipated climate change in order to achieve the design lifespan when construction standards had not been adjusted. This also included costs from mandatory retrofits where the climate impacts pose a hazard to health, as seen in the HVAC system guidelines.

In each of these categories, the underlying concept was to retain the lifespan for the building.

2.5 Stressor-Response Values for New Construction Costs

The determination of building stress-response values was based on specific impacts of precipitation and temperature; however, in addition, the concept of 'incurred costs' is included. Incurred costs are defined as those costs that a building is assumed to incur that cannot be ignored or delayed until a later time. This includes climate impacts on components such as HVAC (Heating, ventilation and air conditioning) systems, which have specific design guidelines based upon factors such as air quality and health of the occupants. In addition to the incurred costs described above, the methodology also incorporates "Adapt" or "No Adapt" options such as roof and drainage adaptations.

2.6 Policy Approach: "Adapt" and "No Adapt" Scenarios

The 'Adapt' analysis assumed perfect foresight with respect to climate change impacts and a policy that applies these forward-looking climate projections to upgrade new buildings as they are re-built and maintained. The 'adapt' approach focused on adjusting building design to improve resilience to climatic impacts. This was the chosen method of analysis for two reasons:

1. It is feasible to assume that the large existing stock of buildings will remain in place in the coming decades and will therefore incur damages that require mitigation; and

2. While many adaptation options were suggested for particularly vulnerable buildings (those in flooding plains, coastal areas, and other vulnerable areas), these options require very specific, localised data and decision making that is outside the scope of a regional and country-level analysis.

The ‘Adapt’ Policy scenario incurs up-front costs to adapt an existing building to mitigate future damages that are projected from increases in precipitation or temperature. Incurred costs are included in this scenario; they are considered as a requirement and as a result are not optional. The ‘No Adapt’ analysis assumed no adaptation changes, i.e. buildings rebuilt according to previous baseline standards. The costs incurred are from increased maintenance necessary to retain the design life of the original building as degradation of the building occurs from climate change stressors. In addition to these overall policy approaches, the maintenance savings from adaptation is considered to emphasise the quantifiable costs and benefits associated with adaptation.

2.7 Building impacts

Based on the types of building analysed for this study and known construction techniques, the methodology for determining impacts focused on non-wooden structures made of steel, masonry, and concrete, which are more resistant to climate impacts (See Table 1). The authors evaluated climate impacts on internal building systems (mechanical and electrical equipment). When evaluating the impacts to HVAC systems, it was assumed that if the airflow systems in the building need to be upgraded due to potential health implications, this upgrade would be undertaken. Although there was an assumption that the impact on external cladding would be minimal, roofing and drainage systems were also analysed. Incurred costs for non-wood structures were calculated using the MEWS Index, which determines climate impacts on HVAC systems (Cornick *et al.*, 2002). The MEWS Index uses a Moisture Index, defined by a Wetting Index (WI) and Drying Index (DI) to calculate the amount of moisture that a building will be subjected to under varying climate conditions. Using this Moisture Index as a basis, the MEWS Index defines the climate region that a structure exists within based on the conditions that it is subjected to during given periods of time. This Index was then normalised to provide an indication of the changes in precipitation or temperature that would be sufficient enough to change the climate condition under which the structure was designed. If the humidity rises above a threshold, the building codes for HVAC load mandate an upgrade of the system to handle airflow for health of the occupants.

2.8 Stressor-Response Values for HVAC adaptation

For each geographic region, a baseline Historic MEWS Index (HMEWS) was calculated and compared to a future Climate Change MEWS Index (CCMEWS) developed from climate information. If the threshold was passed, a cost was applied, based on the cost per square meter of upgrading HVAC for a specific building type.

Table 1: Buildings Impact Formulas for Non-Wood Structures

Independent Climate Factors	Non-Wood Structures
Precipitation Increase	RC; DC; HVAC; EC
Temperature Increase	HVAC
Extreme Flooding Events Increase (Severity and/or Frequency)	RC; DC; EC
Where:	
RC: Increase Roof Water Capacity	DC: Increase Drainage Capacity
HVAC: Upgrade HVAC System	EC: Increased Exterior Cladding Degradation

2.9 Stressor-Response Values for Roofing Adaptation

A second focus was on the potential damage to roofing materials on flat-roofed (typically public) buildings such as hospitals and schools. For these structures, roofing design, specifically drainage systems, is based on projected amounts of water that will exist on the roof from rain events. A failure to adequately size the roofing drain will result in water pooling on the roof. This pooling will result in failure of the roofing material as excessive moisture and standing water will ultimately lead to both material and sealant failure. This stressor-response factor is included

within the current study based on the design parameter of maximum monthly precipitation in a given location. Where the maximum monthly precipitation is anticipated to increase beyond the design parameters, it is determined that a greater precipitation drainage capacity is required. For the Adapt scenario, a larger drainage system is placed on the building with a resulting increase in costs based on total construction costs. This value represents the cost of changing the drainage system within a building prior to construction. For the No Adapt scenario, a similar approach using per cent of total construction cost is employed to determine incurred maintenance costs. This represents the cost of repairing roofing materials that are damaged during precipitation events when system is not initially upgraded. Although precipitation increases can have additional impacts on exterior building components such as windows and doors, the effects on these components are individualised to the building and the conditions in which the building exists. Therefore, these impacts were not included in the current study.

3. Results

The potential impact of climate change on South Africa's public buildings is presented in Table 2. All results are calculated in terms of *costs* to buildings, presented in 2012 USD with no discounting used. The cost figures presented are a one-time adaptation cost for that building. Therefore once a building is adapted (incurred cost), it is assumed that it is sufficiently adapted to survive intact for the remainder of its lifespan, unless another HVAC threshold is exceeded. In other words, when the climate change costs in 2020 are addressed, the costs for 2040 will be lower because as the building was adapted for climate change in 2020, it will not need to be adapted again in 2040.

3.1 National results

The total impact varies between median and maximum scenarios, with schools being the focus of the majority of costs. Using the Median GCM cost projection, the total cost to buildings in USD is 3,419 million and 17,146 Million if the maximum cost impact GCM is used. The projected climate change scenarios do not result in threats to the roof structures that fall under the 'Adapt' and 'No Adapt' scenarios. However, the changes do affect the building systems, resulting in incurred costs for the buildings. Therefore, the results presented here are all incurred costs, which need to be addressed to avoid health and safety issues. From this perspective, using the median scenario, total costs increase steadily from USD\$112 annually in the 2030 decade to over a billion dollars annually by the 2090 decade (see Table 2). It is important to note that these costs apply only to the existing inventory. In this analysis, no growth functions or additional inventory was included. Costs would be much higher if the existing stock was augmented without considering climate change implications.

Table 2: Decadal incurred costs for buildings in USD Million

Mandatory Incurring Costs in USD Million	Hospitals	Schools urban & rural	Public Buildings urban & rural	Total	
2030	Median	2.4	110.0	0.2	112.6
	Maximum	33.9	1,101.2	0.5	1,135.5
2050	Median	14.0	511.3	0.5	525.8
	Maximum	106.4	3,719.5	0.9	3,826.8
2090	Median	39.0	1,167.1	0.6	1,206.8
	Maximum	161.8	5,493.5	1.1	5,656.5

As illustrated, the maximum climate scenario is an order of magnitude greater in impact in the 2030s. Although the difference in magnitude decreases in the 2050s and 2090s, the actual dollar difference continues to increase. By the 2090s, the maximum scenarios present a USD \$4 billion per year difference in incurred costs. This difference leads to the issue of variance in the results. Figure 1 addresses this issue, based on the projected variance in impact on buildings from climate change. As illustrated, it is predicted that the impact will be on the lower end of the variance when the total number of estimates are considered. The lower classification of costs contains 50%, 44%, and 39%

of the total number of estimates in the 2030, 2050, and 2090 decades respectively. Although each scenario is equally likely, from a planning perspective, the skew towards a lower number may provide guidance to consider a lower estimate as a planning tool.

3.2 Provincial Results

At the provincial level, there was significant variation between the provinces in terms of projected impacts of climate change on buildings. Figures 2a and 2b illustrate the total cost for each decade, for each province, and for both the median and maximum climate scenarios. From the median perspective (Figure 2a), the Eastern Cape province was the dominant province in terms of predicted impacts on buildings, with a notable increase beginning in 2060. Significant impacts on buildings were also apparent for the Western Cape province when compared with buildings in the remaining provinces. From the maximum impact scenario (Figure 2b), buildings in the Eastern Cape were once again likely to bare the greatest impact. However, in this scenario, buildings in the Limpopo province emerge as the second most likely to be impacted.

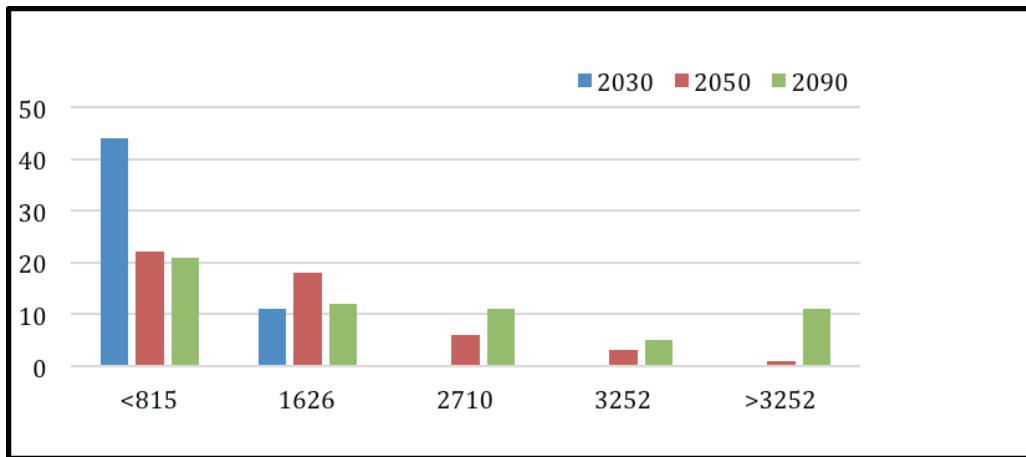


Figure 1: Building impact distribution estimates. Maximum values are labelled in interim histogram categories.

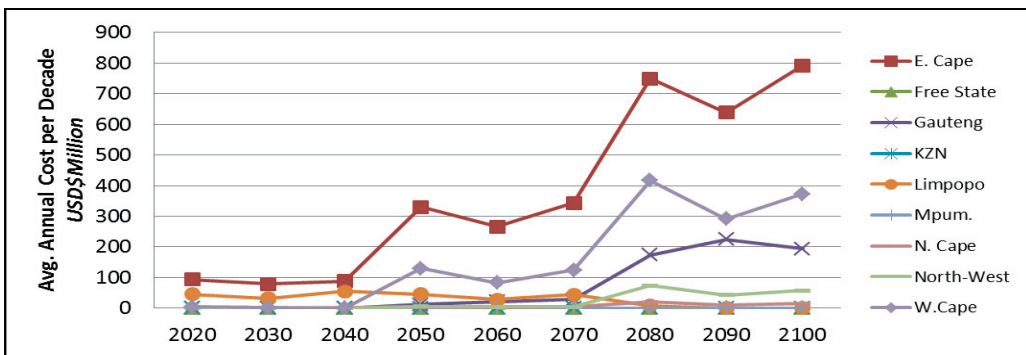


Figure 2a: Incurred costs for buildings by decade (Median GCM)

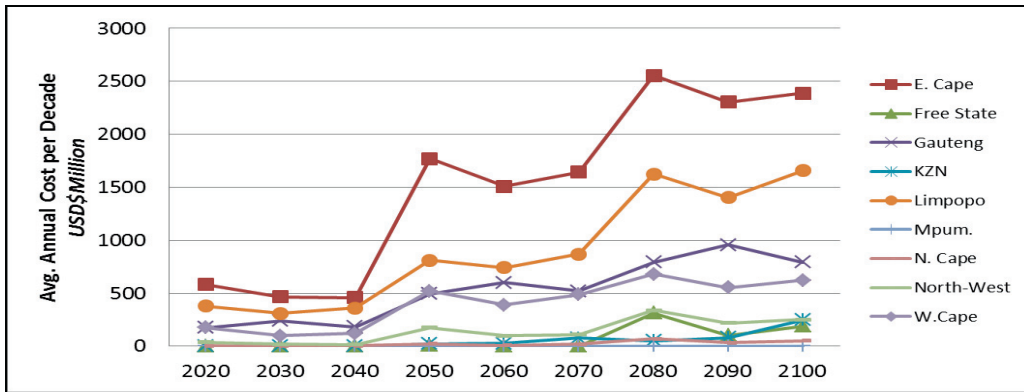


Figure 2b: Incurring costs for buildings by decade (Maximum GCM)

Table 3 illustrates the maximum impact on the provinces in the decade 2050. As illustrated, schools are the most affected due to their sheer number in comparison to hospitals and public buildings. Buildings in the Eastern and Western Cape provinces, as well as the Limpopo province, are predicted to be impacted the most; whilst buildings in the Free State and the Mpumalanga provinces are predicted to be little impacted by climate change.

Table 3: Incurring costs for buildings, 2050 Maximum GCM Scenario

	USD\$ Million	USD\$ Million	USD\$ Million	USD\$ Million
E. Cape	32.0	1,737.1	0.1	1,769.3
Free State	0.3	7.7	0.1	8.1
Gauteng	28.7	465.3	0.2	494.1
Kwa-Zulu Natal	0.6	22.9	0.1	23.6
Limpopo	16.1	796.6	0.1	812.8
Mpumalanga	0.0	0.0	0.0	0.0
Northern Cape	0.9	21.2	0.1	22.2
North West	4.8	170.5	0.1	175.5
Western Cape	23.0	498.2	0.1	521.3

It is important to note the predicted impacts on hospital buildings in the high-impact provinces such as the Eastern and Western Cape and the Limpopo province, as the incurred costs could be directly associated with potential health effects in hospitals over time.

4. Discussion

In this research, South Africa has been used as a case study. However the same research could be applied to data from other countries, in particularly developing countries, in order to support sustainable decision making for the built environment. Whilst climate change will affect everyone, it is expected to have a disproportionate effect on those living in poverty in developing countries. The majority of developing countries are in tropical and sub-tropical regions, areas predicted to be seriously affected by the impacts of climate change: Africa, Asia, Latin America and the Small Island States have all been identified as regions of concern. This is compounded by the fact that developing countries are often less able to cope with adverse climate impacts as poverty exacerbates, and is aggravated by the impacts of environmental change; livelihoods are highly dependent on climate-sensitive resources; and there is considered to be low adaptive capacity (Hayles and Fong, 2008). The research approach presented in this paper, which can be used to help predict climate change impacts on buildings, is also a useful tool in reducing the overall life cycle cost of buildings, despite the fact that minimising the impacts of climate change requires adaptation, an incurred cost to preserve the longevity of existing buildings. The results presented in this paper highlight that Governments (and NGOs) involved in the planning, design, construction and maintenance of building need to consider a number of possible climate change impacts (Hayles and Fong, 2008). Indeed a proactive approach to understanding and addressing these issues may present an opportunity for buildings to be enhanced with alternative, more sustainable technologies, which serve to further decrease vulnerability to climate change impacts.

Meantime research on potential climate change impacts must continue, as current uncertainty is a major impediment to intervention and adaptation. However, given the slow progress and the need for early action in the built environment sector, it is important that the lengthy adaptation process begin now. The construction industry and the public should be shown how adaptation could give worthwhile immediate and short-term benefits in both performance and costs for both new-build and refurbishment projects. If people demanded ‘best practice’ instead of ‘barely legal’, defined by building codes and standards, then climate change impacts would be reduced going forward (Camilleri et al., 2001).

5. Conclusions

The study presented in this paper examined the potential effects of climate change on municipal buildings South Africa. The study focused on using an engineering approach to determining the specific effects of climate stressors on municipal buildings. Based on a combination of actual and estimated totals for each province within South Africa, the study illustrates the variance in local effects as well as projections from differing climate scenarios. Overall, the study found that total impact on buildings in South Africa would vary between USD \$42.7 million average annual costs in the median scenario and USD \$214.3 million average annual costs in the maximum scenario. However costs would be much higher if the existing stock was augmented without considering climate change. Therefore the results not only highlight the increasing costs of climate change over time, they demonstrate the need for better consideration in the planning and design of new buildings to reduce life cycle costs in the future. The results from this research are intended to inform the economic models that comprehensively analyse the effects of climate change on the economy of South Africa. Similar research could be used to support sustainable decision-making in other countries. The resulting challenge to any local, regional, and national government agencies is how to incorporate a multitude of conflicting requirements into a cohesive policy that achieves balance between short-term needs and the potential long-term effects of climate change on buildings.

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