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The impact of housing type on temperature-related mortality in South Africa, 1996–2015

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ABSTRACT

This paper explores how housing modifies the temperature–mortality relationship in the Eastern and Western Cape provinces of South Africa. We estimate dose–response relationships for residents living in each of the five common types of South African housing by combining linear-threshold models for Cape Town with concurrent data on the city's housing composition and expert estimates of how well different types of housing protect against heat and cold. We then apply temperature data to determine provincial-level dose–response relationships, relative risks, attributable fractions and mortality burdens for heat and cold under seven housing scenarios – three past, three future and a scenario of maximum protection. We find that future mortality burdens would be lower under a policy scenario that prioritizes the replacement of informal housing compared to one that prioritizes the replacement of traditional dwellings. In a maximum protection scenario, where everyone lived in houses characteristic of the wealthy, temperature-related mortality could be reduced by over 50% (approximately 5000 deaths annually) in the two provinces combined. These results have relevance to current housing policy but also reinforce the importance of the built environment in mitigating adverse effects of future climate change.

1. Introduction

The temperature–mortality relationship is relatively well-studied in developed countries and has experienced a resurgence of interest in the context of climate change (Basu and Samet, 2002). However, fewer studies have focused on developing countries, with a conspicuous shortage of research on how environmental factors may modify the association.

A prominent feature in many developing countries is an ongoing shift in housing types, with much of the transition a consequence of urbanization (United Nations Human Settlements Programme, 2003). Despite the considerable scale of this shift, the impact of the change in housing on the temperature–mortality association remains largely unexplored. Limited evidence from developed countries suggests that the built environment may be an important modifier of the association, and authors have speculated the same for developing countries (Ballester et al., 2003; Curriero et al., 2002; McMichael et al., 2008; O'Neill et al., 2005; Sharovsky et al., 2004; Wilkinson et al., 2001). Unless this is considered, unplanned development may inadvertently increase the risk of temperature-related mortality (McMichael et al., 2008).

South Africa represents an appropriate case study to investigate how housing influences temperature-related mortality for three reasons. First, there is extreme variability in the types of South African housing. Second, the proportion of South Africans living in the different types of housing is changing; in addition to an urban growth rate of around 2% per year (United Nations, 2010), the post-1994 government has prioritized low-cost housing provision (Department of Housing, 1994; Goebel, 2007). The government has already delivered nearly three million "formal" houses to low-income South Africans and aims to provide a further 220 000 units annually in the coming years (Sexwale, 2010). And third, other developing countries may eventually undergo similar housing transitions to what South Africa is experiencing currently.

The objective of this paper is to begin to explore how housing may modify the temperature–mortality relationship by using the Eastern Cape and Western Cape provinces of South Africa as a case study. The neighboring provinces were chosen for comparison because of their relatively comparable climates, but radically different housing composition; over a third of households live in traditional dwellings in the Eastern Cape compared to less than 1% in the Western Cape (Statistics South Africa, 2005; Statistics South Africa, 2008).

2. Methods

Risk assessments are generally organized into four stages: hazard identification, dose–response assessment, exposure assessment and risk characterization (Samet et al., 1998). The methods for each stage are described below, beginning with the

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dose–response assessment; an association between temperature and mortality is well known and has been reviewed elsewhere (Basu and Samet, 2002).

Although the temperature–mortality relationship has been quantified for numerous locations around the world, the only published time-series study quantifying a dose–response relationship in South Africa is for the city of Cape Town, located in the Western Cape (McMichael et al., 2008). One co-author of the previous publication has recently published as a PhD thesis a more detailed analysis for this relationship in Cape Town, and we use this data as a basis for extrapolation to housing- and scenario-specific dose–response relationships; linear threshold models of all-cause mortality show a 2.91% (95% CI 1.82,4.02) increase in mortality per degree below a cold threshold of 18 °C (95% CI 17,19), lagged 3–13 day and a 1.64% (95% CI 0.83,2.45) increase per degree above a heat threshold of 19 °C (95% CI 18,21), lagged 0–2 day (Kovats, 2010).

The exposure assessment involved two steps. The first step was to identify the proportion of the South African population living in different housing types in each province at each of the years 1996, 2001 and 2007. Information was available from census data (1996, 2001) and the 2007 Community Survey (Statistics South Africa, 2005; Statistics South Africa, 2008). Census and Survey outputs summarize housing into five categories: formal, informal, traditional, backyard/shared and other.

Three changes are made to these categories for the purposes of this assessment. First, the ‘‘other’’ category, made up of tents, boats, caravans, etc. is excluded from all analyses due to its indeterminate variety and small contribution to total housing. Second, ‘‘backyard/shared’’ housing is amalgamated into the ‘‘formal’’ category, as census meta-data define it as a form of formal housing (Statistics South Africa, 2003).

Third, because of the size of the group and corresponding diversity within it, formal housing is separated into three sub-categories: ‘‘formal wealthy’’, ‘‘formal middle-class’’ and ‘‘formal low-cost’’. The sub-categories were defined by splitting the formal category into six equal quantiles and assigning three to the ‘‘low-cost’’ group, two to the ‘‘middle-class’’ group and one to the ‘‘wealthy’’ group. In other words, half the formal households are considered ‘‘low-cost’’, a third ‘‘middle class’’ and the remaining sixth ‘‘wealthy’’ (see Supplemental Material, Section 1 for a discussion of evidence for the validity of this procedure).

Briefly, ‘‘formal wealthy’’ and ‘‘formal middle-class’’ housings are similar to their equivalent classes of housing in most industrialized nations, although built for local climate and rarely feature centralized heating or cooling systems. Space heaters, fireplaces and fans are common. ‘‘Formal low cost’’ housing tends to be built from cement walls and a corrugated iron roof. Informal housing (shacks) may be constructed from a variety of materials, though corrugated iron (walls and roof) is common. Traditional dwellings normally feature a wood–clay or stone–clay combination for the walls and a thatched roof.

The second step of the exposure assessment was to quantify the sheltering capability of the five housing categories. To do this, five experts in environmental health and/or the built environment participated in a form of expert elicitation. The experts were asked, through a structured questionnaire, to estimate the percent of protection each type of housing conferred against cold- or heat-related mortality compared to no housing at all. The questionnaire included descriptions of the housing categories and a short summary of published evidence of their thermal performance (see Supplemental Material, Section 2 for the questionnaire and Supplemental Material Section 3 for information about respondents).

The risk characterization stage integrates the dose–response and exposure assessments to outline the changing burden of mortality attributable to temperature under different housing scenarios. Seven housing scenarios are examined (Table 1), each detailing the relative risks, attributable fractions and expected mortality burdens under that scenario for both the Eastern and Western Cape. The first three scenarios represent the known housing makeup of each province in 1996, 2001 and 2007. Three other scenarios are hypothetical future scenarios in 2015; one is a ‘‘projected’’ scenario based directly on previous housing trends, one is an ‘‘urban’’ scenario, meant to represent a policy where most new low-cost housings replace informal housing, and the last is a ‘‘rural’’ scenario where most new housings replace traditional dwellings. The last scenario is a ‘‘maximum protection’’ scenario and assumes that everybody lives in formal wealthy housing.

The impacts of each scenario on mortality are compared using the daily mean temperatures averaged over the 10 year period 1999–2008, as recorded at the Cape Town International Airport weather monitoring station and accessed from the National Climatic Data Center, US Department of Commerce (National Climatic Data Center, 2009). (For example, the temperature for 1 January is the mean of the mean temperature for each of the 10 days dated 1 January from 1999–2008.) Similarly, to simplify comparisons, attributable mortality calculations for all scenarios use the total annual provincial deaths from 2008, the most recent data available, which was 83 159 for the Eastern Cape and 46 728 for the Western Cape (Statistics South Africa, 2010).

The method for determining the dose-response relationships, relative risks and attributable burdens for all scenarios in the two provinces over time can be described in three sequential steps. All equations derive from published expressions (Armstrong and Darnton, 2008; Steenland and Armstrong, 2006).

Step 1: Constructing the dose–response relationship for different housing scenarios

The first step toward characterizing the temperature-related mortality is to determine the dose–response relationship (the excess mortality per degree above or below the minimum mortality thresholds) for each province under the different scenarios. By assuming that all factors modifying the effect of temperature on mortality are equally distributed throughout the study area, with the exception of housing, the temperature effects in any area are determined by the following equations:

$$X_{\text{cold}} = M_{\text{cold}} \sum_{j=1}^{5} Wj(1-P_{j(\text{cold})}) \quad \text{and} \quad X_{\text{heat}} = M_{\text{heat}} \sum_{j=1}^{5} W_j(1-P_{j(\text{heat})}) \qquad (1a, 1b)$$

where $W_j = (N_j/N_{\text{total}})$ and X is the % excess mortality (% increase in mortality per degree above/below threshold) in a given population; M the average % excess mortality (% increase in mortality per degree above/below threshold) without housing (constant across scenarios); N_j the number of households of a given type in the study area; N_{total} the total households in the study area.

Therefore, W_j can be thought of as the weight applied to each housing type obtained from its proportion in the study area.

P_j the percent of protection against cold/heat for each housing type (constant across scenarios). Therefore, $(1-P_j)$ is the percent of residual excess risk of mortality due to temperature.

J represents the five housing categories previously described (formal wealthy, formal middle-class, formal low-cost, informal and traditional).

In other words, if the average excess mortality per degree heat or cold in the absence of housing, M, were known, and each housing type confers a known degree of protection against temperature-related mortality, P_j, then multiplying M by the percent of residual risk of temperature-related mortality in the population, as determined by the housing composition, gives the excess mortality in the population, X.

Consequently, because an estimate of the excess mortality (X) for Cape Town is available, as well as the concurrent proportions (W_j) of Cape Town residents living in different housing types (City of Cape Town, undated), and the protective factors (P_j), estimated in the elicitation exercise (see Section 3.1), Eqs. (1a) and (1b) can be used to obtain an estimate of M (see Supplemental Material, Section 4, for details of this calculation). Once M is known, the excess mortality for the Eastern and Western Cape can be determined for the different scenarios simply by altering the proportions of the different housing types, Wj, accordingly (M and P_j remain constant across scenarios).

Step 2: Calculating the attributable fraction

To determine the attributable fraction, we need to know the average daily relative risk over the year, which depends on X (the % increase in mortality per degree above/below threshold) and the temperature distribution. It is calculated as follows:

$$RR_{\text{ave(cold)}} = \frac{\exp[X_{\text{cold}}(T_{\text{cold}}-t_i)^+]}{365} \quad \text{and} \quad RR_{\text{ave(heat)}} = \frac{\exp[X\text{heat}(t_i-T_{\text{heat}})^+]}{365} \qquad (2a, 2b)$$

where RR_{ave} is the average daily relative risk from cold or heat; X the excess mortality (% increase per degree above/below threshold); t_i the mean daily temperature (lag 3–13 for cold and lag 0–2 for heat); T the threshold temperature at which adverse effects of cold or heat on mortality commence.

$(T_{\text{cold}}-t_i)^+$ indicates that $(T_{\text{cold}}-t_i)^+$ is equal to the maximum of $(T_{\text{cold}}-t_i)$ or 0. Therefore, all days with a mean temperature above the cold threshold are assigned a relative risk of 1. The heat equation is adapted accordingly.

Once the average daily relative risk is established, the attributable fraction (AF) is calculated from the following (Steenland and Armstrong, 2006):

$$AF = \frac{(RR_{\text{ave}}-1)}{RR_{\text{ave}}} \qquad (3)$$

Table 1
The seven housing scenarios explored in the risk characterization.

Past scenarios:
Scenario 1: Housing composition in 1996.
Scenario 2: Housing composition in 2001.
Scenario 3: Housing composition in 2007.
Future scenarios – 2015:
Scenario 4 – ‘‘Projected’’ – Average annual growth rates (1996–2007) in the five housing categories continue until 2015.
Scenario 5 – ‘‘Urban’’ – Assumes the government supplies low-cost formal housing from 2008–2015 at the at the 2008/09 rate (Department of Human Settlements Undated) 85% of this housing replaces informal housing with the remaining 15% replacing traditional dwellings. No other housing changes occur. If a housing type is completely replaced prior to 2015, all subsequent new housing replaces the remaining type from that point forward.
Scenario 6 – ‘‘Rural’’ – As Scenario 5 except 85% of the supply replaces traditional dwellings with the remaining 15% replacing informal housing.
Scenario 7 – ‘‘Maximum Protection’’ – Assumes everybody lives in formal wealthy housing.