# Climate change and health: A study of indoor heat exposure in vulnerable populations in Detroit, Michigan

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## Introduction

- Long term climate change may result in even more heat related illness and death
- Studies show the elderly are more vulnerable to heat, especially those over the age of 65 years
- Indoor temperatures are more likely to represent accurately the exposure of the vulnerable individuals to heat, given their likelihood to stay indoors. (Smargiassi et al. 2008)
- Limited number of published studies have addressed indoor heat exposure in residences occupied by an elderly population

## Objectives

- To develop a mathematical model that can be used to predict indoor temperatures using weather characteristics, housing characteristics and environmental surroundings
- To determine what specific housing and environmental characteristics put the elderly more at risk for indoor heat exposure
- To determine how the elderly adapt to hot weather(data not shown)

## Methods

- City of Detroit residents were recruited to participate in the summer long study (June 1 – September 1, 2009) based on:
  - ➢ Age (over 65 years)
  - ➢ Housing type (single family home, two family flat, high rise apartment (more than 2 floors))
  - ➢ Air conditioning status (central air conditioning, no central air, room air conditioning)
  - ➢ Geographic location
- Various data sources were used to develop the model

| Data | Source |
|---|---|
| Housing Characteristics Data | Detroit Property Tax Assessment Office, visual assessment |
| Indoor Temperatures | HOBO Temperature Loggers (recorded temperatures at 0.5 hour intervals) |
| Solar Radiation | Michigan Automated Weather Network |
| Behavioral Data | Volunteer Activity Logs |
| Outdoor Temperatures | Detroit Metropolitan Airport Archives |

- Study was approved by University of Michigan Institutional Review Board. Analysis completed with SAS Statistical software version 9.2 (SAS Corporation, Cary, North Carolina) and ArcGIS version 9.3.

## Study Sample Details

- 77% of the homes started indoor temperature monitoring by June 22, 2009. Summary statistics for the homes are shown below.

| Occupancy Type | # (%) | Exterior construction | #(%) |
|---|---|---|---|
| Single Family | 18(60%) | Brick | 26 (87%) |
| Two Family Flat | 3 (10%) | Asphalt | 2 (7%) |
| Highrise | 9 (30%) | Woodsiding | 1 (3%) |
| | | Vinylpaneling | 1(3%) |

| Date of Construction | # (%) | Rooms Monitored | #(%) |
|---|---|---|---|
| Built before 1940 | 14 (47%) | Bedrooms | 24 (41%) |
| 1940 or later | 16 (53%) | Other | 35 (59%) |

| Prevailing Surroundings | # (%) |
|---|---|
| Residential | 12 (40%) |
| Urban | 5(17%) |
| Yard/Park | 8(27%) |
| Concrete | 5(17%) |

## Building the Predictive Model

- General energy balance of a home, based on simple physics principals.

$$C\frac{Tin_{(t)} - Tin_{(t-\Delta t)}}{\Delta t} = S_{adsorption(t)} * R_{global(t)} + R_{o,in} - (h_o + f_{open} * h_v) * (T_{in(t)} - T_{out(t)})$$

- General physics model was transformed into the mixed effects regression model. The three parameters that were used and could significantly contribute to analyzing the sensitivity of each home were:
  - ➢ Outdoor temperature (ToutDayAvg)
  - ➢ Solar Radiation (SolDayAvg)
  - ➢ Previous midnight temperature (TprmidAvg)
- From this general energy balance, the following mixed effects regression model was created to get the average effect across the sample of 30 houses in Detroit, as well as the house-specific parameter estimates.

**Mixed Effect Regression Model (Daily Averages)**

$$T_{RmsDayAvg}(t) = \beta_0 + \beta_1 * T_{OutDayAvg} + \beta_2 * R_{SolDayAvg} + \beta_3 * T_{TprmidAvg} + \varepsilon_t$$

- Proc Mixed command in SAS to generate effect estimates for each parameter. For our purposes, the effect estimates from the mixed model represent a measure of "sensitivity".
  - ➢ Higher effect estimates suggest how sensitive a change in indoor temperature is due to one of the parameters.

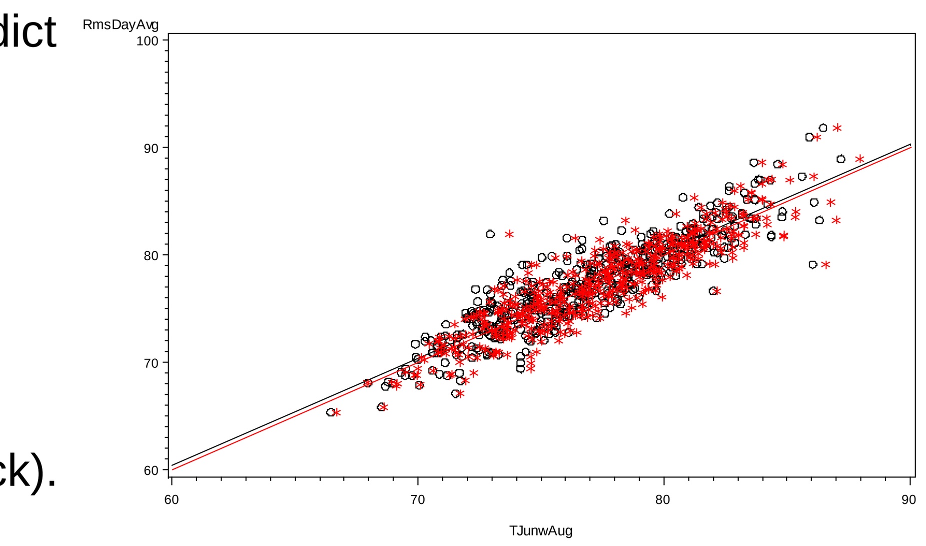
$$\cdot \beta_1 = \frac{S_{absorption}(t)}{\frac{C}{\Delta t} + (h_0 + f_{open} \cdot h_v)}, \cdot \beta_2 = \frac{\frac{C}{\Delta t}}{\frac{C}{\Delta t} + (h_0 + f_{open} \cdot h_v)}, \cdot \beta_3 = \frac{(h_0 + f_{open} \cdot h_v)}{\frac{C}{\Delta t} + (h_0 + f_{open} \cdot h_v)}$$

## Results

### Predictive Model

- Our final mathematical model can be used to predict indoor temperatures, regardless of month, for the Detroit residences.
- The scatterplot to the right shows a close linear relationship between actual indoor temperatures recorded in each home (y-axis), versus the indoor temperatures predicted by the (1) the regression parameters for the June model (in red) and, (2) the regression parameters for the August model (in black).

**Plot of Actual June Temperatures vs. Predicted and Modeled**




### Measuring risk of indoor heat exposure by parameter sensitivity

- Based on observations made in this study, people that are living in homes constructed of vinylpaneling or woodsiding are more sensitive to outdoor temperature changes and internal heat gains, despite having prevailing surroundings defined as "yard/park" vs. "concrete". Homes made of asphalt show a higher sensitivity to the previous midnight temperature and could hold in more heat than a home made of brick.

| | n | Intercept (Internal gains) | Outdoor Temperature | Solar Radiation | Previous midnight temperature |
|---|---|---|---|---|---|
| Average of all locations | 30 | **9.62 | **1.47 | -0.09 | **0.61 |
| Brick | 26 | **12.43 | **1.47 | -0.22 | **0.57 |
| Asphalt | 2 | -5.23 | **1.28 | 0.78 | **0.84 |
| Vinylpaneling | 1 | **33.02 | **2.74 | -1.70 | 0.07 |
| Woodsiding | 1 | *8.12 | **2.90 | -0.61 | **0.36 |

- People that are living in high rises with at least one room that is air conditioned are more protected from outdoor temperatures than a standard home.

| | n | Intercept (Internal heat) | Outdoor Temperature | Solar Radiation | Previous midnight temperature |
|---|---|---|---|---|---|
| Average over all locations | 29 | **26.24 | **1.87 | *-0.34 | **0.33 |
| High Rise | 9 | **36.84 | *1.17 | -0.43 | **0.33 |
| Non High Rise | 20 | **21.62 | **2.19 | -0.30 | **0.33 |

- Locations without central air conditioning are more sensitive to outdoor temperatures and solar radiation. Non-bedrooms (living rooms, dens, dining rooms) located on the 1st floor were more sensitive to indoor temperature changes for every parameter, compared to non-bedrooms not on the 1st floor.

## Conclusions and Future Directions

- Urban surface imperviousness, thermal emissivity and population density are parameters that could be integrated into the model to determine their effect on the sensitivity of indoor temperature in specific homes.
- Hourly behavioral data was logged by each resident and will be analyzed, within the model, to learn what temperatures "trigger" behaviors to maintain a comfortable indoor temperature.
- The mixed regression model can be refined by obtaining detailed housing characteristics (i.e. insulation type, wall structure, window type) enhance model predictability.
- The results of this pilot study will provide valuable information on how different housing stock within the city of Detroit responds to heat. The results can be used to substantiate the need for policies and practices around home weatherization or greening activities for the elderly that live in single family homes .

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