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# BUBBLE WRAP OR SLIPPERS? THAT IS THE QUESTION: FROM HAMLET TO HOME INSULATION

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There has been much publicity about New Zealand houses having indoor temperatures below World Health Organization standards and how insulation can benefit the health and comfort of the occupants. Landlords are required to install underfloor and ceiling insulation. In Christchurch, in some council flats, it has been suggested that commercial insulation is not practical and too expensive to retrofit, and tenants have been asked to use bubble wrap on windows. So, does bubble wrap actually improve interior comfort? In this study, air temperatures were measured in a typical New Zealand, three bedrooms, 100 $m^2$, 1960s house. A heat-pump in the living room was set to heat to 18 ºC. Bubble wrap was applied to bedroom windows during the winter and spring of 2019. Temperatures were compared to 2016 data, which was prior to the installation of the bubble wrap. Regression analysis was employed to determine if the bubble-wrap had any effect on air temperature by either reducing variability or improving average temperatures.

*Keywords*: Temperature, Housing, Thermal, Retrofit, Glazing.

## 1 INTRODUCTION AND BACKGROUND

In New Zealand, many people, and indeed at least one social housing provider (Ineson 2018), have suggested that a very cost-effective way to improve the insulation of houses may be to apply bubble wrap to windows, particularly in bedrooms where reduced visibility is acceptable. Anecdotally, it is not uncommon for occupants to report that they feel warmer (Reporter 2012).

Bubble wrap has been suggested for insulation in industrial, experimental, medical, and domestic settings. In the USA, aluminum lined bubble wrap is recommended for lining the walls of pig barns to reduce energy use and condensation and to prevent frosting (Jacobson 2011). Bubble wrap formed part of the thermal insulation and condensation barrier (Abdulsada and Salih 2015) for a passive house experiment in Iraq. Researchers from two American universities suggest that bubble wrap could help save energy in greenhouses with little impact on light transmission (Runkle *et al.* 2011). Laboratory experiments with glass and polypropylene double-glazed units modified with the addition of various interlayers were described in (Gibson 2019). The results showed that two interlayers of bubble wrap reduced radiation and convection more effectively than air-filled double and triple glazing.

The purpose behind all insulation is to reduce heat transfer by conduction, radiation, and convection. It appears that bubble wrap may have the potential for improving window insulation and this paper aims to quantify any temperature changes attributable to installing bubble wrap on windows of a minimally insulated unoccupied weatherboard house in Christchurch, New Zealand.

## 2 METHODS

### 2.1 Initial Setup

In early 2016, 16 temperature sensors (ITEAD 2017), (accuracy ±0.5 ºC) were installed recording air temperature at two heights in the bedrooms of a typical New Zealand construction, minimally insulated 1960s weatherboard house in central Christchurch, New Zealand (Greenan and Muir 2017, Mulligan *et al.* 2019). This house has an area of 100 $m^2$ comprising three bedrooms and a connected/open plan kitchen and living space. A wall-mounted air source heat pump (Daikin, model FVXS50LVMAt) in the living room (at the center of the house) is programmed to automatically turn on when an internal temperature sensor detects a temperature less than 18 ºC. Doors are kept open between rooms.

In July 2019, bubble wrap was installed on the interior window frames in the three bedrooms of the house. The windows are single pane clear glass and the bubble wrap results in an air gap of the interior frame thickness (~15mm).

### 2.2 Data Collection

Between 4th July and 31st August in 2016 and 2019 (59 days), temperatures were logged at 5-minute intervals. Each sensor is uniquely identified by the factors "room" (Bedroom 1, Bedroom 2, Bedroom 3) and "height" above interior floor level (low (200 mm) and medium (1500 mm)). Temperatures were averaged for the periods: morning (7 – 9 am), day (9 am – 5 pm), evening (5 – 11 pm), night (11 pm – 7 am) (French *et al.* 2006). Outside hourly temperatures were obtained from the closest appropriate NIWA weather station in Kyle Street, Christchurch (3 km from the house) (National Institute of Water and Atmospheric Research 2013).

### 2.3 Data Analysis

The data were checked and analyzed using R software (R Core Team 2017). Welch two-sample *t*-tests were used to determine whether there were any significant differences between outside temperature time period averages in 2016 and 2019. An *F*-test was used to determine whether outside temperature time period averages were equally variable in both years.

**Does bubble wrap reduce variability in temperatures?** Differences between interior and outside average temperatures were calculated. To determine whether the variability of these temperature differences changed once bubble wrap was installed, a two-sided *F*-test was used to test the null hypothesis that the ratio of 2016 (without bubble wrap) and 2019 (with bubble wrap) temperature difference variances was equal to 1.

**Regression analysis:** A linear and log-linear multiple regression analysis was used to explore relationships between medium and low interior time period average temperatures (ºC) and outside temperatures (ºC) while quantifying the effects of bubble wrap (installed or not installed); time period (morning, day, evening, night) and room (Bedrooms 1, 2 and 3). Averages were time period averages. Four models were considered and are further described in the results section: ***Model IOLinear***; ***Model MOLog***; ***Model LOLog*** and ***Model MLLinear.***

## 3 RESULTS

**3.1 Comparison of Outside Temperatures in 2016 and 2019:** There was no significant difference in the 2016 and 2019 average outside temperatures and variability (Figure 1) ($p > 0.05$).

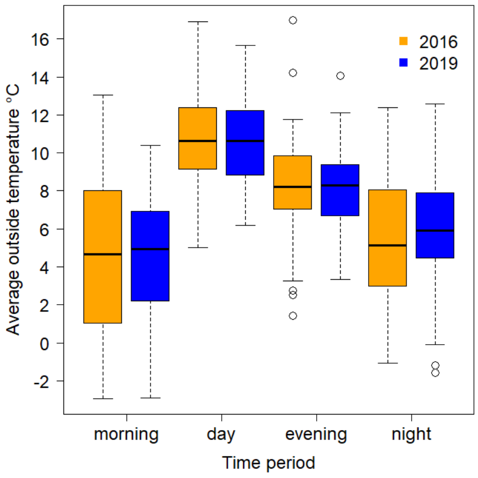

Figure 1. Comparison of time period average outside temperatures (°C) in 2016 and 2019.

### 3.2 Did Bubble Wrap Reduce Variability in Interior Temperatures?

During the day and evening, the 2016 (no bubble wrap) average differences (between interior and outside temperatures) were significantly more variable when compared with 2019 (bubble wrap installed) ($p < 0.01$). However, during the morning and night, there were no significant differences in the variability between the 2016 and 2019 interior and outside temperatures differences. A reduction in variability as measured in the day and evening may be the reason that anecdotally occupants perceive that bubble wrap enhances comfort.

### 3.3 Regression Analysis

Figures 2, 3, and 4 show the interior sensor data related to the outside temperature, colored for bubble wrap, time period, and room effects. Figure 5 shows the medium interior sensor data related to the low interior sensor. In general, there was a significant linear relationship between model predictors (i.e., outside temperature, bubble wrap, time period, and room) and interior sensor temperatures ($p < 0.001$) with the exception of evening temperatures in ***Model MOLog***.

***Model IOLinear*** **(**$sensor = \beta_0 + \beta_1 \times outside\ temp$). **Interior sensor average temperatures (medium and low) related to outside average temperatures:** The interior sensor average temperatures were 15 °C (medium) and 11 °C (low) when the outside average temperature was zero and increased by 0.3 °C (medium) and 0.43 °C (low) for every 1 °C increase in outside temperature. However, ***Model MLLinear*** only explains 49% of the variation in medium sensor average temperatures, mostly due to the variability of temperature sensors increasing as outside temperatures increase ($R^2 = 0.49$, $F(1,1414) = 1368$, $p < 2.2\times10^{-16}$). This variation was reduced by taking logarithms of the response variable (***Model MOLog*** and ***Model LOLog***).

***Model MOLog*** **and** ***Model LOLog*** **(**$\log_e sensor = \beta_0 + \beta_1 \times outside\ temp + \beta_2 \times bubble\ wrap + \beta_3 \times time\ period + \beta_4 \times room$). **Logarithms of interior sensor average temperatures (medium and low) related to outside average temperatures with bubble wrap, time period and room effects:** The percentage of variation in medium and low sensor average temperatures explained was 65% (***Model MOLog***) and 75% (***Model LOLog***) ($p < 2.2\times10^{-16}$). During the day in Bedroom 1, without bubble wrap applied to windows, when the outside temperature was zero degrees, the average interior temperature was 17 °C (medium) and 12 °C (low). For each increase of one degree in the outside temperature, medium sensors increased by 1.1% and low sensors increased by 2.4%.

*Bubble wrap effects* are depicted in Figures 2(a) (medium sensors) and 2(b) (low sensors). The installation of bubble wrap increased interior sensor average temperatures by 1.4% (medium) and 4.1% (low), implying that bubble wrap has more of an effect on low sensor average temperature compared to medium sensor average temperatures. At outside temperatures of 5, 10, and 20 degrees this would be a respective 0.07, 0.14, and 0.28 ºC increase in medium sensor temperature and a respective 0.21, 0.41, and 0.82 ºC increase in low sensor temperature. So, even though bubble wrap statistically increases average temperatures, the magnitude of the increases would not be noticed by an occupant and are within the accuracy of the sensors.

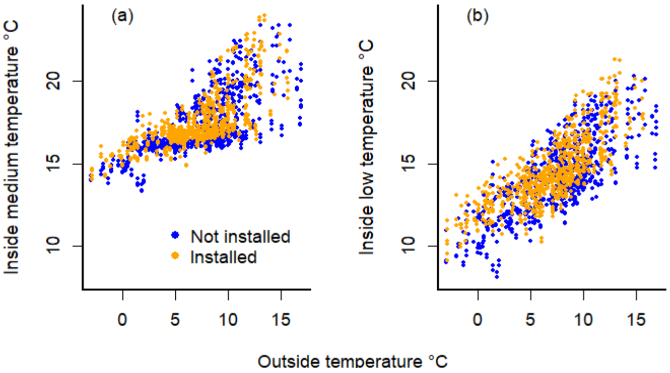

Figure 2. Interior sensor average temperatures (medium and low) related to outside average temperatures, colored to show bubble wrap effects.

*Time period effects* are depicted in Figures 3(a) (medium sensors) and 3(b) (low sensors). Mornings, evenings, and nights recorded significantly cooler medium sensor average temperatures compared to daytime temperatures (10.5%, 4.5%, and 9.6% lower, respectively). For low sensors, evening temperatures were not significantly different from daytime temperatures. Mornings and nights were all significantly cooler than daytime temperatures (10.1% and 7.8% lower, respectively).

*Room effects* are depicted in Figures 4(a) (medium sensors) and 4(b) (low sensors). For medium sensor temperatures, Bedrooms 2 and 3 were colder than Bedroom 1 (1.4% and 2.3%, respectively). For low-temperature sensors, Bedroom 2 was warmer than Bedroom 1 (6.5%) and Bedroom 3 was colder (2.8%).

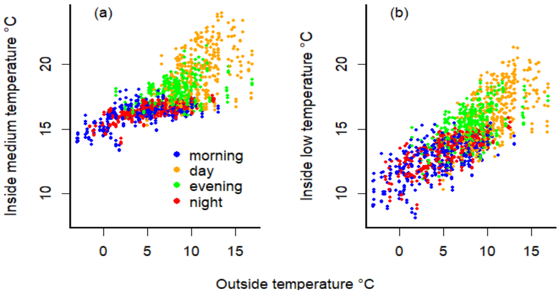

Figure 3. Interior sensor average temperatures (medium and low) related to outside average temperatures, colored to show time period effects.

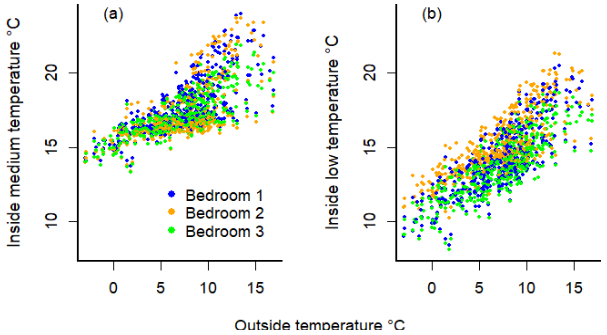

Figure 4. Interior sensor average temperatures (medium and low) related to outside average temperatures, colored to show room effects.

***Model MLLinear*** (*med* = $\beta_0 + \beta_1 \times$ *low* + $\beta_2 \times$ *bubble wrap* + $\beta_3 \times$ *time period* + $\beta_4 \times$ *room*)**. Interior medium sensor average temperatures related to low sensor average temperatures with bubble wrap, time period and room effects:** Low sensor average temperatures were a good predictor of medium sensor average temperatures as shown in Figure 5 (93% of variation explained ($R^2 = 0.93$, $F(7,1408) = 2791$, $p < 2.2\times10^{-16}$)).

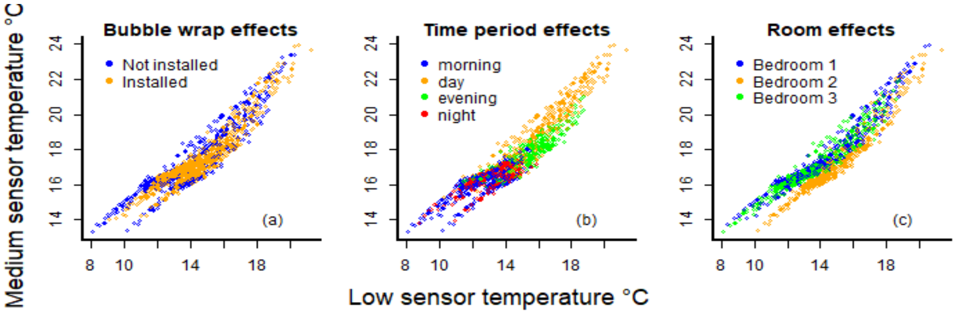

Figure 5. Relationship between the medium sensor average temperatures and the low sensor average temperature (***Model MLLinear***).

During the day, in Bedroom 1, with no bubble wrap installed, when the low sensor average temperature was zero degrees, the model predicts an average medium sensor of 7.2 ºC. For each increase of one degree in the low sensor temperature, medium sensors increased by 0.8 ºC. The coldest low sensor time period average temperature recorded was 8.1 ºC in the morning. This corresponds to an average medium temperature of 13.7 ºC, i.e., a 5.6 ºC difference between medium and low average temperatures. There was significant bubble wrap, time period, and room effects (Figures 3(a), (b) and (c) respectively), all reducing the difference between medium and low sensor averages, but all effects were less than 0.9 ºC and would not be noticeable to an occupant.

Figure 3(c) shows Bedroom 2 had cooler medium sensor temperatures (compared to Bedrooms 1 and 3) when the low sensors were recording less than approximately 13 ºC. When compared with Figure 3(a), bubble wrap did not appear to have any effect in Bedroom 2 (orange and blue markers coincide on the Bedroom 3 data points 'line'). Whereas bubble wrap appears to lessen the difference between medium and low sensors in Bedrooms 1 and 3 (orange markers lie below blue markers on Bedroom 1 and 3 data points 'line').

## 4 CONCLUSION

When bubble wrap was installed on bedroom windows, the bedroom sensor average temperatures were increased by 1.4% (medium height sensors) and 4.1% (low height sensors). In degree terms, however, this is a negligible difference (less than 0.9 degrees) and would unlikely be noticed by an occupant. There is evidence that during the day and evening, bubble wrap decreases the variability of the differences between interior and outside temperatures.

There is up to a maximum of a 5.6 ºC temperature difference between medium and low temperature sensors, particularly on colder days in the morning. Since the medium and low sensors are 1500 and 200 mm off the floor, respectively, this would be likely to cause discomfort to occupants (cold feet). Rather than issuing tenants with bubble wrap as insulation, councils might be better placed to issue slippers.

The next stage of this research is to place curtains over the door frames to isolate the effect of the heat pump on the bedrooms.

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