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Keeping our children warm and dry: Evidence from *Growing Up in New Zealand*

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Purpose of report

This report represents the final report from a collaborative project commissioned by BRANZ working in partnership with the *Growing Up in New Zealand* research team. This study was conducted after the success of the pilot study that tested the feasibility of utilising different methods to collect temperature and humidity information from the homes of children in the cohort during 2017.

The children collected indoor climate (temperature and humidity) information about their home and school environments as an added component to a routine data collection wave of the longitudinal study when they were approximately eight years old. The primary aim of collecting these measurements was to enable an examination of the association between measured indoor climates and child health and sociodemographic variables collected over time.

Given that New Zealand children's health and wellbeing is impacted by indoor environmental conditions, we specifically wished to determine: (1) direct measures of the indoor environmental conditions experienced by the children at the individual level and (2) evaluate any associations between these direct measures and existing longitudinal child health and family sociodemographic variables. These analyses were designed to provide evidence that could contribute to strategies for improving indoor environments with a view to potentially enhancing the health and wellbeing of all New Zealand children and their families.

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We thank all the members of the *Growing Up in New Zealand* research team for their invaluable work collecting and preparing all the data used for analyses in this report, and especially acknowledge team members who assisted with extraction and cleaning of the indoor environmental measures from the Time Use Diaries completed by the cohort children.

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Further information about the *Growing Up in New Zealand* team, governance and design of this longitudinal study is available on our website: www.growingup.co.nz

Executive Summary

In 1982, the World Health Organization (WHO) initiated a working group to review the current scientific evidence on optimal indoor temperature and develop guidance for protecting the health of people (WHO 1984). The working group recommended a housing temperature range between 18°C and 24°C (Ormandy and Ezratty 2012). The WHO has specified this same temperature range in later published reports (WHO 1987; WHO 1990) and further recommended a minimum indoor temperature of 20°C for the most vulnerable populations (Ormandy and Ezratty 2012). In 2006, the WHO reported that the health evidence for the guidance on what constitutes a safe indoor temperature range was relatively weak. In 2018, the WHO strongly recommended the minimum indoor temperature of 18°C for countries with temperate or colder climates; and recommended (on a conditional level) to develop and implement strategies against excess indoor heat without specifying the maximum indoor temperature (WHO 2018). Research evidence on the optimal indoor temperature range using actual indoor climate measures is still regarded as limited (Jevons *et al.* 2016; Tham *et al.* 2020) and direct evidence specific to children's health and wellbeing has not been reported.

The specific aim of the present population-based study was to directly measure indoor temperature and relative humidity in the homes and classrooms of eight-year-old children who are part of the ongoing *Growing Up in New Zealand* (GUiNZ) longitudinal cohort study. The advantage of measuring these indoor environments in this cohort was that it would enable direct measures of temperature and humidity from the children's homes and schools to be linked to existing longitudinal information about their overall health and wellbeing in the context of their family and household environments. This individual level analysis was also designed to help provide new knowledge to inform what constitutes an optimal indoor climate range for supporting the wellbeing of contemporary New Zealand children.

For this study, we utilised indoor measurements collected by the children in the cohort at specified times of the day and on selected dates (as an adjunct to the core eight-year data collection wave). We also undertook linkage to routine NIWA (The National Institute of Water and Atmospheric Research) outdoor measurement variables at similar time points to the times the children collected their measures to assess how indoor climates were related to external climactic conditions. We explored how these environmental variables were associated with multiple measures of child physical and psychological wellbeing available as part of the ongoing longitudinal data collection for the *Growing Up in New Zealand* study. We further examined how indoor climates varied according to the sociodemographic characteristics of the children and their families, measured at the eight-year data collection wave.

Multiple analyses were undertaken as part of this exploration to better understand the association between actual indoor temperatures and concurrent child wellbeing at eight years of age. Overall, we were most interested in finding U-shaped exposure-response patterns between the indoor temperature measures and child wellbeing outcomes to determine an optimal range for indoor environments for this age group.

While a number of measures recorded by the children were significantly associated with health outcomes, we determined that the most sensitive, in terms of predicting differences in wellbeing across the cohort, were from the readings taken at bedtime on a weekday. Further research is needed to examine why this reading was most sensitive but some evidence for the importance of overnight indoor climate variability and in-bed temperatures has been found by Saeki *et al.* (2015). In terms of wellbeing the most sensitive measure was the general health status reported by the children's mothers at the time of the eight-year interview. This wellbeing measure was also likely to be the most proximal in terms of the time when the indoor measurements were taken and recorded by the children.

Accordingly, we have used these measures of indoor climate (weekday bedtime) and wellbeing (general health status) throughout this report to illustrate the findings of these exploratory analyses. Detailed analyses were also undertaken to try to determine the optimal indoor climate range for supporting child wellbeing across this diverse cohort. Temperature and humidity measures were considered together, and the optimal range determined for this group of children was between a minimum temperature of 19°C and a maximum Humidex of 28. We were also able to show that children who experienced the greatest disadvantage across a range of familial sociodemographic measures were most likely to be exposed to indoor climates that did not meet this range.

To our knowledge, the present study is the first in the world to combine temperature as the lower and Humidex as the higher cut-off point to describe an optimal indoor climate range. The evidence from this novel study has also directly linked measures taken in children's homes and schools with their wellbeing and the influence of socioeconomic outcomes. The advantages of sample size and longitudinal cohort data in combination with direct climate measures makes this study highly informative both in a NZ and worldwide context. In NZ it is also salient for policy considerations as our findings are relevant to existing legislation related to housing quality and healthy homes in New

Zealand, including the *Building Code (Interior Environment – Performance)* and the *Residential Tenancies (Healthy Homes Standards) Regulations* 2019.

This bespoke research and report represents a beginning in terms of investigating indoor climates that children in the *Growing Up in New Zealand* cohort experience on a daily basis. Over time it is hoped that recordings of indoor environments might be feasibly made over a longer time period, rather than just two days. Additionally, as the children get older it is hoped that they will be able to record more detailed measurements more accurately and in greater numbers so we might consider how the findings from this initial study may vary over time, as home environments change and potentially as new strategies to improve indoor environments are implemented. We look forward to undertaking further research in these areas in partnership with BRANZ and other key stakeholders as may be appropriate.

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Abbreviations

Abbreviations	Meaning
Weekday – Wake up	When the child first woke up in the morning
Weekday – School	When the child arrived in school classroom in the morning
Weekday – Lunch	During the child's school lunchbreak
Weekday – Home	When the child arrived home from school
Weekday – Bed	Before the child went to sleep at night
Weekend – Wake up	When the child first woke up in the morning
Weekend – Dinner	When the child had dinner
Weekend – Bed	When the child went to sleep at night
95CI	95% confidence intervals
BRANZ	Building Research Association of New Zealand
CHAOS	Family environment, Confusion, Hubbub and Order Scale
CESD-10	10-item short form Centre for Epidemiologic Studies Depression Scale
CO_2	Carbon dioxide (ppm)
DAG	Directed acyclic graph
DCW	Data collection wave
Dep-17	Ministry of Social Development's 17-item material deprivation index
GEE	Generalised Estimating Equation
GUiNZ	*Growing Up in New Zealand*
IQR	Interquartile range
MSD	Ministry of Social Development
MWI	Material Wellbeing Index
n	Sample size (analysis specific)
NIWA	The National Institute of Water and Atmospheric Research
NZDep	New Zealand's area level Deprivation index
NZiDep	New Zealand Deprivation at an individual level
OR	Odds ratio
PROMIS	Patient-Reported Outcomes Measurement Information System
RCT	Randomised controlled trial
RH	Relative humidity (%)
SD	Standard deviation

T	Temperature (°C)
TUD	Time use diary
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

1 Introduction

The importance of the quality of indoor environments for population health and wellbeing has been recognised globally. The United States Environmental Protection Agency (USEPA) previously recognised poor indoor air quality as an important environmental hazard for the western world (Taptiklis and Phipps 2017). Hence, understanding the potential risks posed by exposure to poor indoor climates has become an increasingly important research area for improving wellbeing globally (White and Jones 2017).

On average, New Zealanders spend around 70% of their daily time in indoor home environments (Khajehzadeh & Vale, 2017). However, the Building Research Association of New Zealand (BRANZ) latest House Condition Survey from 2015 (which included data from 560 houses in New Zealand) reported that many New Zealand indoor home environments were of poor quality. For example, 53% of the houses in the survey lacked adequate insulation, 46% did not heat occupied bedrooms in winter and only 15% reported heating bedrooms regularly overnight (White and Jones 2017). This is problematic as poor indoor climate can have significant harmful consequences on occupants' health.

Further specific analyses of the pilot information for this project, which used information collected from the Leading Light group of families in the *Growing Up in New Zealand* (*GUiNZ*) cohort during the eight-year data collection wave (DCW) in 2016, also found that children's homes were not adequately heated. This pilot study found that children are regularly exposed to homes with high levels of dampness and/or condensation (20% of homes), mould (12% of homes), unflued gas heaters (12% of homes) and wood-burners (25% of homes). Of particular relevance to this report, 40% of the Leading Light cohort were waking up in the morning to temperatures below 18°C. Taken together, these diverse findings suggest many New Zealand children and families may be regularly exposed to suboptimal indoor environmental conditions.

Children spend a significant amount of their time indoors, either at home or at school in their classrooms (Anderson and Bogdan 2007; Franklin, 2007). Hence, to better understand the impact of indoor environments on children's health and wellbeing it is important to understand more about the specific home and school indoor environments that children in New Zealand are currently experiencing.

There are several measures that can act as proxy measures of the quality of the indoor environment. Temperature and humidity are two important indicators used for assessing the quality of an indoor environment. While guidelines are available for optimal indoor conditions, the evidence to support what represents an optimal range for such measures and the applicability of existing guidelines for supporting children's wellbeing remains under-researched. In 1982, the World Health Organization (WHO) initiated a working group to review the current scientific evidence on optimal indoor temperature and develop guidance for protecting the health of people (WHO 1984). The working group recommended a housing temperature range between 18°C and 24°C (Ormandy and Ezratty 2012). The WHO has specified this same temperature range in later published reports (WHO 1987; WHO 1990) and further recommended a minimum indoor temperature of 20°C for the most vulnerable populations (Ormandy and Ezratty 2012). In 2006, the WHO reported that the health evidence for the guidance on what constitutes a safe indoor temperature range was relatively weak. In 2018, the WHO strongly recommended the minimum indoor temperature of 18°C for countries with temperate or colder climates; and recommended (on a conditional level) to develop and implement strategies against excess indoor heat without specifying the maximum indoor temperature (WHO 2018). Research evidence on the optimal indoor temperature range using actual indoor climate measures is still regarded as limited (Jevons *et al.* 2016; Tham *et al.* 2020). In the New Zealand context, there is little direct evidence about what constitutes an optimal indoor environment, in terms of both temperature and humidity, for supporting children's acute and long-term wellbeing.

The purpose of this current project was therefore to directly measure indoor climates in the homes and in the classrooms of contemporary New Zealand children who are part of The *Growing Up in New Zealand* longitudinal cohort study. This bespoke project, supported by BRANZ, set out to collect multiple indoor climate measures from the homes and schools of up to 6000 main cohort children as part of the eight-year DCW that was undertaken between 2017 and 2019.

These individual level indoor climate measures were then able to be considered alongside concurrent measures of wellbeing collected from the cohort in middle childhood. Analyses comparing indoor climates with wellbeing measures were used to define an optimal indoor environmental climate range (using temperature and humidity) for supporting the cohort children's wellbeing. Additionally, the likelihood that a child experienced these optimal indoor environments was explored according to family socio-demographic factors, also collected directly from the cohort.

1.1 The *Growing Up in New Zealand* study overview

GUiNZ is a longitudinal study that provides contemporary, population-relevant information to understand what shapes the development and wellbeing of children growing up in New Zealand in the 21st century. The study recruited the cohort via pregnant mothers and their partners, beginning data collection during the cohort mother's pregnancy, with multiple DCWs carried out during the children's early years. The *GUiNZ* cohort is unique in terms of its size and diversity, and its ability to provide evidence across multiple domains of influence on developmental trajectories for contemporary New Zealand children. In particular, the cohort includes significant numbers of Māori, Pacific and Asian children as well as children expected to identify as New Zealand European, as identified by their parents in very early life (Morton *et al.* 2012).

The model of child development shaping this study is child-centred and acknowledges that children develop over time in dynamic interaction with their families, communities, informal and formal environments, and societal and political contexts. The conceptual framework also acknowledges the importance of the physical environment for shaping health and wellbeing. Importantly with respect to this bespoke study, the indoor environments that children are exposed to in their early years constitute key influences on their wellbeing outcomes.

The existing longitudinal, multi-disciplinary information means that as well as collecting individual climate information, the socio-demographic, social and home factors associated with differential measures could also be explored.

1.1.1 The *Growing Up in New Zealand* cohort

The children in the *GUiNZ* cohort were recruited via their pregnant mothers in 2009 and 2010. The mothers were required to have expected delivery dates between the 25th of April 2009 and the 25th of March 2010 and be residing in the geographical areas defined by the three contiguous District Health Board regions (DHBs) of Auckland, Counties Manukau, and Waikato during their pregnancy. The cohort recruited was designed to be of sufficient size to have adequate statistical power for complex analyses of developmental trajectories over time across the whole cohort of children as well as within key subgroups (including by ethnicity and area-level deprivation).

A potential cohort of 6853 cohort children was recruited at baseline with an additional 200 children, born in late 2008 recruited to be part of the 'Leading Light: Te Roopu Piata' group. Further information about the cohort, recruitment and retention, and alignment of the cohort with current New Zealand births can be accessed at www.growingup.co.nz.

1.1.2 Data collection waves

From its inception, the *GUiNZ* study has been explicitly designed to follow children from before birth until they are young adults, to understand what 'works' for children and families as well as what creates challenges for their wellbeing. The timing of DCWs, and what is measured (from whom and how) in *GUiNZ* are all planned according to the study's conceptual framework, overarching objectives, and multidisciplinary research questions (Morton *et al.* 2012). Each specific DCW provides a snapshot of information at one cross-sectional point in time and is designed to add valuable age and context-specific information to understand the ongoing development of contemporary New Zealand children. The study has ethical approval from the Ministry of Health Ethics Committee (NTY 08/06/055), and this is updated for each new DCW.

Each DCW seeks age-appropriate information across six inter-connected domains: family and whānau; societal context, neighbourhood, and environment; education; health and wellbeing; psychosocial and cognitive development; and culture and identity. Attention is given to ensuring the methods used to collect domain-specific evidence appropriately acknowledge the unique New Zealand population and environmental context, particularly the opportunity *GUiNZ* presents to examine the factors that contribute to the wellbeing of whānau and tamariki Māori.

1.1.3 The eight-year data collection wave

The eight-year DCW was the first time the *GUiNZ* cohort children completed their own questionnaire. Hence, for the first time in the study we were able to hear the children's voices directly, as well as what they thought about their identity (including their ethnicity), their health and wellbeing, their relationships and what matters most to them. The interviews were conducted with the children and their parents in their homes between July 2017 and January 2019 when the children were mostly eight years old (mean age = 8.6 years). The eligible child cohort for the eight-year DCW included 6571 of the 6853 children originally recruited into the *GUiNZ* cohort (96% of the baseline child cohort).

Overall *GUiNZ* has achieved high participation rates at all face-to-face DCWs with 76% (n=5241) of the baseline birth cohort completing every face-to-face DCW. In total 81% (n=5556) of the eligible cohort (which excluded children who had died or children whose parents had opted them out of the study prior to the latest wave) participated in the eight-year DCW (Morton *et al.* 2020).

2 Objectives for the BRANZ research

The current bespoke project, in partnership with BRANZ, aimed to measure indoor climate (temperature and humidity) as part of the *GUiNZ* eight-year DCW to enable an examination of the association of indoor climate measures with child health outcomes. The bespoke project aimed to address three main research questions:

1. To determine the optimal range of indoor environment (temperature and humidity) for children in New Zealand for supporting health and wellbeing.
2. Understanding better the association between measures of home indoor environments and the health and wellbeing of young New Zealand children.
3. Understanding the sociodemographic and home environment factors associated with optimal indoor climates of New Zealand children.

3 Methods

3.1 Measures

3.1.1 Indoor temperature and relative humidity data collection

Indoor temperature and relative humidity data were collected directly by children in the *GUiNZ* cohort using a small handheld digital temperature and relative humidity gauge (attached to a lanyard). Measurements were entered into a time use diary (TUD) that collected multiple other measures of children's daily activities (not reported further here). The children were also provided with a pen which included a digital clock to enable them to accurately record the times indoor environmental measurements were taken. These specific components were provided to the children in their home by trained interviewers as part of their eight-year routine interview process. The children were asked to follow the instructions in the TUD to record temperature and relative humidity readings at eight different time points across one weekday and one weekend day and enter this into their diaries.

The scheduled times for recording temperature and relative humidity readings on the *weekday* included:

- when the child first woke up in the morning (Weekday - Wake up)
- when the child arrived in school classroom in the morning (Weekday – School)

- during the child's school lunchbreak (Weekday – Lunch)
- when the child arrived home from school (Weekday – Home)
- before the child went to sleep at night (Weekday – Bed)

The scheduled times on the *weekend* day included:

- when the child first woke up in the morning (Weekend - Wake up)
- when the child had dinner (Weekend – Dinner)
- when the child went to sleep at night (Weekend – Bed)

3.1.2 Linkage to routine climate measures (NIWA data)

Based on the geographical cluster of the home location and also making an assumption that the location of the children's school was usually within close geographical proximity (which is the case for most children in the cohort), we matched the eight indoor measurements taken by the children with the hourly outdoor temperature and relative humidity data recorded by NIWA weather stations representing the local climate at the children's homes (details in Appendix A). Since outdoor data were a proxy of the local area and not measured at individual home locations, the linked outdoor climate data were primarily used as a covariate in the models for outlier detection.

3.1.3 Temperature and humidity data cleaning and outlier detection

The measurements of the indoor environments and their entry into the TUD were completed by the children following their 8-year interview home visit. Once the diaries were as complete as possible the children and their parents were asked to return their completed diaries to the study team by post using a supplied pre-paid envelope. Unfortunately, not all the children in the cohort were able to complete and/or return their diaries, however a considerable number (over 2000) were returned. Characteristics of the children who did return diaries and the associated information used in this report are detailed further in Section 4. Indoor environment measures represented only a fraction of the information that the children provided in their TUDs, however only these measures are explored further in this report.

3.1.3.1 Data cleaning

Recorded indoor environment measures were entered according to the information recorded by the children in the TUD. Cleaning of data included a combination of automated and manual methods to prepare the four main types of information used in these analyses (date, time, temperature, and humidity). Further detail about the methods used to clean the raw data can be found in Appendix B.

3.1.3.2 *Outlier detection*

The time, temperature and humidity data used in the data analyses also underwent a process to check their validity and outliers were removed prior to further analyses (see Appendix C). Initially this involved each timed data point being assessed in relation to all other time data points to determine if they followed the expected sequential temporal pattern (Weekday: wake up, before school, lunchtime, after school, bedtime. Weekend day: wake up, dinner time, bedtime). If one of these records did not follow the sequential pattern, the out of sequence measurement value was replaced by the median of all values recorded for that time point across the cohort. The 4-sigma rule (Peterson *et al.* 1998) was then applied to the time data whereby any values that were more than ±4 times the standard deviation away from the mean were removed.

Outlier detection for temperature and humidity data also utilised Lund's test (Lund 1975) whereby a Generalised Estimating Equation (GEE) was undertaken to generate residual values. The GEE used indoor temperature or humidity as the outcome variable and five covariates: outdoor temperature/humidity, year, month and hour of measurement, and a measure of individual household deprivation (NZiDep) at the 54-month DCW. This was based on the assumption that indoor climate variables would be affected by a combination of the outdoor climate, annual trend, season and time the measurement was taken, as well as factors known to vary according to individual household deprivation such as insulation, heating availability, and housing quality (Howden-Chapman *et al.* 2012).

Less than 1% of all measures were removed using these two outlier detection methods (Appendix C).

3.1.3.3 *Final variables used for analysis*

After data cleaning and removal of outliers, the climate measurement dataset in this project included two date variables, eight time variables, 16 indoor measurement variables, 16 NIWA outdoor measurement variables, and 32 derived variables for indoor climate (16 statistical variables + 16 variables combined from temperature and relative humidity). These variables included standard deviation, interquartile range, minimum, maximum, range and median, as well as the average value of wake up and bedtime on both weekday and weekend, used to indicate the average sleep time. At each of the eight time points, we also combined both the temperature and relative humidity values to calculate the vapour pressure and then Humidex (Appendix D).

3.1.4 Child health and wellbeing outcomes measured in eight-year DCW

In this project, we included 20 child health and wellbeing outcomes measured during the eight-year DCW. These outcomes were either originally measured as, or transformed into, binary variables (yes or no) in the data analyses.

Sixteen of these 20 outcomes were child-proxy (parent-reported) physical health of the cohort children recalled over different time periods (either over the last 12 months or in the past one month or recorded on the interview day). The measures are summarised below in Table 1.

3.1.4.1 Physical health outcomes

For physical health, outcome variables were derived from the 8-year child-proxy questionnaire reported by the cohort child's mother. These included questions about the child's general health as well as questions about common childhood illnesses the child had experienced in the last 12 months and if they had been prescribed antibiotics (Table 1).

The common illness outcomes were based on one question ("*Which, if any, of these common childhood illnesses has {the child} had in the last 12 months?*") that included the following options:

- Non-food allergies
- Hay fever
- *Ear infections
- *Asthma
- *Whooping cough or pertussis
- *Other respiratory disorders (including chest infections, bronchiolitis, bronchitis, pneumonia)
- *Coughing lasting more than four weeks
- *Wheezing in the chest
- Gastroenteritis (≥3 watery or looser-than-normal bowel movements or diarrhoea within a 24-hr period)
- Eczema or dermatitis
- *Throat infection or tonsillitis
- Skin infections (where the skin is red or warm or painful or swollen, or there are pustules or boils or crusting or oozing).

The question on child physical health was a tick all that apply option and for analysis purposes the reference group for these illnesses was 'no' if maternal report indicated the child had not had a specific illness (Table 1). If any outcomes with an asterisk (*) were recorded they were classified as being respiratory outcomes. An additional respiratory outcome was derived from two questions ("*When was the most recent course of antibiotics?*" and "*What was the main reason {the child} was on antibiotics most recently?*"). Those who had the most recent course completed within the last month due to respiratory-related illnesses (ear infection or respiratory or chest infection, bronchiolitis, bronchitis, pneumonia, throat infection or tonsillitis) were also defined as having experienced this respiratory outcome. Note both upper and lower respiratory infections have been included in the definition of the child having experienced a respiratory-related illness (see Craig *et al.* 2013).

In order to fully assess maternal reported child health status (child-proxy), two dichotomized outcomes were derived from the same standardised general health question ("*In general, how would you say {the child}'s current health is?*"). Suboptimal/poorer general health was defined as those who responded as "Good", "Fair" or "Poor" (using "Excellent" or "Very good" as reference). Poor general health was defined as those who responded as "Fair" or "Poor" (using "Excellent" or "Very good" or "Good" as reference) (Table 1).

3.1.4.2 Mental health outcomes

For assessing child mental health, four outcomes were derived from the final scores that were calculated from child's self-reported depression and anxiety levels in the "past seven days". In the *Now We Are Eight* report (Morton *et al.* 2020), these two measures were reported as continuous variables due to insufficient validation studies in New Zealand at the time of reporting to determine clinically-relevant cut-offs for child's depression and anxiety outcomes. For consistency and comparability across all other selected outcome measures in our data analyses in this project, we applied bespoke cut-offs to transform these two outcome measures into binary variables that **only** reflect the likelihood of having higher than average scores for depression and anxiety rather than the likelihood of clinically having these outcomes (table 1).

3.1.4.2.1 Child Depression

A short-form of the original 20-item Centre for Epidemiologic Studies Depression Scale was used to assess child depression. The 10-item short from (CESD-10; Andresen *et al.* 1994) is scored on a 4-point scale with anchors ranging from 0 (Not at all) to 3 (A lot) with two reverse-coded items. Preliminary findings suggest that CESD-10 is an acceptable tool for screening depression in adolescents (Bradley *et al.* 2010).

3.1.4.2.2 Child Anxiety

The Pediatric PROMIS Anxiety short form questionnaire was used to assess children's anxiety symptoms (Irwin *et al.* 2010). All items use a seven day recall timeframe prefaced with "in the past seven days" and a five point response scale (never (0), almost never (1), sometimes (2), often (3) and almost always (4)). The eight anxiety items from PROMIS anxiety short form reflect fear, worry and hyperarousal (Irwin *et al.* 2010) and these items have been found to be sufficient in providing a precise measure for indicating anxiety symptoms in children.

Table 1. Health and wellbeing outcome measures included in this project.

Time frame for child report	Measure of child health (binary)	Specific question asked (to define yes)
Last year (12 months)	Non-food allergies (Ref: no)	The child had non-food allergies in the last 12 months
	Hay-fever (Ref: no)	The child had hay-fever in the last 12 months
	*Ear infections (Ref: no)	The child had ear infections in the last 12 months
	*Asthma (Ref: no)	The child had asthma in the last 12 months
	*Whooping cough or pertussis (Ref: no)	The child had whooping cough and pertussis in the last 12 months
	*Other respiratory disorders (Ref: no)	The child had other respiratory disorders (including chest infections, bronchiolitis, bronchitis pneumonia) in the last 12 months
	*Cough lasting > 4 weeks (Ref: no)	The child had coughing lasting more than four weeks in the last 12 months
	*Wheezing in the chest (Ref: no)	The child had wheezing in the chest in the last 12 months
	Gastroenteritis (Ref: no)	The child had gastroenteritis (3 or more watery or looser-than-normal bowel movement or diarrhoea within a 24-hour period) in the last 12 months
	Eczema or dermatitis (Ref: no)	The child had eczema or dermatitis in the last 12 months
	*Throat infection or tonsillitis (Ref: no)	The child had throat infection or tonsillitis in the last 12 months
	Skin infections (Ref: no)	The child had skin infections (where the skin is red or warm or painful or swollen, or there are pustules or boils, or crusting or oozing) in the last 12 months
	Respiratory illnesses (Ref: no)	The child had any outcome(s) with an asterisk (*) noted above in the last 12 months
Past month (30 days)	Antibiotics for respiratory (Ref: no)	The child had completed a recent course of antibiotics within the last month due to any respiratory-related illness(es) (including ear infection, respiratory or chest infection, bronchiolitis, bronchitis, pneumonia, throat infection or tonsillitis)
Past week (7 days)	Higher depression score (Ref: <10)	The child had a CESD-10 score of 10 or higher based on 10 validated questions on how the child felt in the past week
	Higher anxiety score (Ref: <65)	The child had a PROMIS (short form) score of 65 or higher based on 8 validated questions on how the child felt in the past 7 days
	Highest decile in depression score (Ref: <13)	The child had a CESD-10 score of 13 or higher (highest decile) based on 10 validated questions on how the child felt in the past week
	Highest decile in anxiety score (Ref: <61)	The child had a PROMIS (short form) score of 61 (highest decile) or higher based on 8 validated questions on how the child felt in the past 7 days
Current (at interview)	Poorer General health (Ref: Excellent / Very Good)	The child's concurrent health was reported by their mother as generally poor, fair or good.
	Poor General health (Ref: Excellent / Very Good / Good)	The child's concurrent health was reported by their mother as generally poor or fair.

3.1.1 Sociodemographic factors assessed in 8-year DCW

In order to fully assess sociodemographic variables pertinent to our research questions we included 25 variables in our data analyses. These variables describe key elements related to the home environment including material deprivation, housing quality and household finances, parenting time and parental support, and maternal health and wellbeing. The factors we have used are listed in Table 2 below.

We have included two proxy measures to assess exposure to poverty or disadvantage - the Material Wellbeing Index (MWI) and Dep-17 index (Perry, 2017). These two indices provide an indication of the family's access to essential items and can be used as proxy indicators of whether their basic daily needs can usually be met.

Table 2. Sociodemographic variables included in data analyses.

	Variables	**Specific question asked**
Home environment	Number of people living in the house	Total number people living in the house (including children, adolescent or young adults aged 20 or under, and adults aged 21 or above)
	Number of bedrooms in the house	Total number of bedrooms in the house - including rooms used as bedrooms e.g. lounge, garage
	Crowding (average number of people per bedroom)	Total number of people divided by total number of bedrooms
	Non-bedroom areas used for regular sleeping	Use of rooms or areas other than bedrooms (e.g. lounges, living spaces, caravans, garages, sleep outs) for regular sleeping
	Home environment is like a "zoo"	The mother responded "*very much like your own home*", "*somewhat like your own home*", "*a little bit like your own home*", or "*not at all like your own home*" towards a statement "*It's a real 'zoo' in our home*"- one of the 15 items from the Family environment, Confusion, Hubbub and Order Scale (CHAOS)
	Put up with feeling cold to reduce cost	The mother answered "*Not at all*", "*A little*", or "*A lot*" in response to whether she had put up with feeling cold to keep down costs in the last 12 months
	House problem: dampness or mould	The mother answered "*Major problem*", "*Minor problem*", or "*No problem*" in response to whether the accommodation had any problems with dampness or mould in the last 12 months
	House problem: heating / keep warm in winter	The mother answered "*Major problem*", "*Minor problem*", or "*No problem*" in response to whether the accommodation had any problems with heating and/or keeping warm in winter in the last 12 months
Material deprivation	Household affordability to eat properly	The mother answered "*Always*", "*Sometimes*" or "*Never*" in response to how often her household could afford to eat properly over the past year
	Household food runs out due to lack of money	The mother answered "*Often*", "*Sometimes*" or "*Never*" in response to how often her household ran out of food due to lack of money over the past year
	Material Wellbeing Index percentile rank*	The mother's score in Material Wellbeing Index (24-items) was translated to percentile rank in the New Zealand population (lower percentile means more deprived) (see Appendix E)
	Dep-17 Material Hardship Index	The mother's score in Dep-17 Material Hardship Index (17-items) (higher score means more deprived)

Table 2 (continued). Sociodemographic variables included in data analyses.

	Variables	Specific question asked
Housing and finance	Owning or partly owning the house/flat	The mother responded "*Yes*" or "*No*" to a question "*Do you or anyone else who lives there, own or partly own the house/flat you live in (with or without a mortgage)?*"
	Paying rent / mortgage for the house/flat	This is a variable combined from two questions. It shows the mother's "*Yes*" response to a question "*Do you, or anyone else who lives with you, make mortgage payments for the house/flat you live in?*", otherwise, it shows the mother's response to a second question "*Do you, or anyone else who lives with you, pay rent to an owner or to an agent for this house/flat you live in?*" This variable reflects the current burdens on housing cost in terms of mortgage or rental payment.
	Household income total (before tax)	The mother's response to a question "*In the last 12 months what was your household's total income, before tax or anything else was taken out of it? Please include your personal income in this total.*"
	Household debt total (excl. mortgage / home loan)	The mother's response to a question "*Thinking about all the debt that your household may have (excluding your mortgage/home loan). What is the approximate combined total value of debt that you currently have?*"
Parenting time and support	Mother's working hours per week	The mother's response to a question "*Including overtime, how many hours a week do you usually work in all your jobs?*"
	Mother's work schedule regularity	The mother's response to a question "Which of these best describes your current work schedule(s)?". Options include "*A regular daytime schedule*", "*A regular evening shift*", "*A regular night shift*", "*A rotating shift*", "*Split shift*", "*On call*", "*Irregular schedule*", "*Casual hours*"
	Mother's work hour flexibility	The mother's response to a question "*Is it possible for you to work flexible hours?*"
	Mother having enough support for parenting the child	The mother's response to a question "*How often do you feel that you have enough support for parenting your Growing Up in New Zealand child/children?*"
	Mother having a current partner	The mother's response to a question "*Do you have a current partner?*"
Maternal health and wellbeing	Mother's self-perceived health status	The mother's 5-point scale (poor to excellent) response to a question "*In general, would you say your health is…?*"
	Mother's mental health (anxiety / depression / other)	The mother's response of "*Anxiety*", "*Depression*" or "*Other mental health condition*" to a question "*Please can you tell us whether you are currently affected by any of the following illnesses, disabilities or medical conditions diagnosed and/or treated by a doctor?*"
Demographic	Child's sex	Gender (male or female) of her child in the study – perinatally and reviewed at 8 year pre-interview call
	Child's ethnicity	Child's self-prioritised ethnicity at 8 years (note included a potential response of "*I don't think about it*")

To answer the research questions, we investigated the combination of the 48 indoor measured climate variables (16 original measurements + 32 derived variables) and the 42 variables from the 8-year cohort data used to describe the child's health and wellbeing outcomes (17 variables) and the sociodemographic and home environment factors (25 variables). A five staged approach was used for these analyses - as described below.

3.2 The five stage analytical methods

We applied a reductionist approach and developed a five stage analytical methodology (involving pattern detection and prioritisation principles) to limit the number of unlikely patterns of associations in the data. This allowed us to conduct more in-depth analyses on specific exposure-response relationships in later stages. This is essential for pattern recognition, in the process of determining whether a threshold (or cut-off point) exists or not. This potentially minimises misclassification errors before we assess the associations with sociodemographic and home environment factors. Our five-stage analytical methodology is depicted in Figure 1Figure 1. The five stages of data analyses.

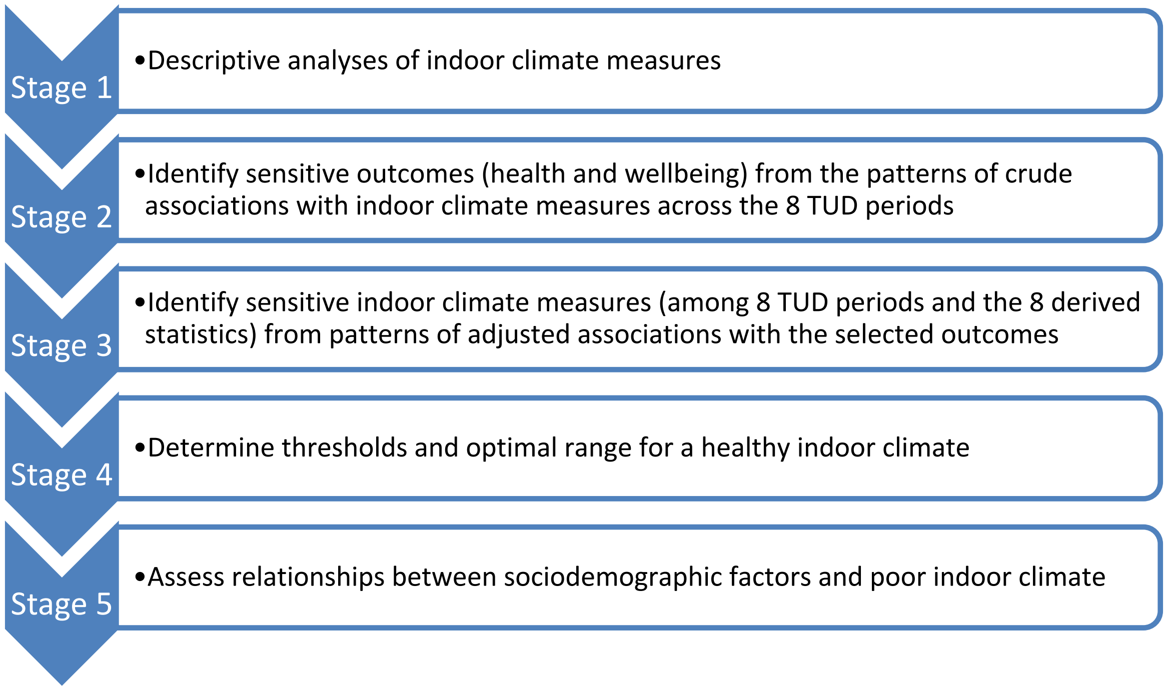


Figure 1. The five stages of data analyses

3.2.1 Stage 1

In Stage 1 variables were created to describe the central tendency and variability of all of the indoor climate variables as measured by the cohort children in their homes and schools. These measures were compared with the outdoor climate data obtained via linkage to the NIWA weather station data. Each of the variables were measured at different times or dates across the period of the *GUiNZ* DCW. Therefore, we also presented the data by time and date to demonstrate the variation in measures across the 12 month data collection and measurement period. Quintiles for each variable were described and these were used in Stage 2.

3.2.2 Stage 2

Stage 2 examined child health and wellbeing outcomes associated with indoor climate measurements and created derived measures to summarise the complexity of outcomes for use in further analyses. The 20 binary health outcomes and quintiles for the eight temperature variables (as described in Stage 1) were first assessed using the Chi-Square test to determine if the proportions of those experiencing an adverse health outcome differed by temperature quintile (Chi-Square $P<0.05$). Those variables passing this initial screening were then assessed using logistic regression analyses to determine if the upper or lower temperature quintiles differed from the middle temperature quintile (reference) in terms of the odds of experiencing each health outcome. We hypothesised that the association between temperature quintile and the health outcomes would be non-linear (U- or V- or J-shape) such that there would be increased odds of experiencing adverse health outcomes for both warmer and cooler temperature quintiles compared to the reference middle quintile (Braga *et al.* 2002, Armstrong 2006; Barnett 2015). Under this hypothesis, we focused on associations with an exposure-response relationship that was bi-directional (with an observable turning point within the measurement range) or unidirectional (assumed the turning point has not been captured by the measurement range). Only statistically significant associations with patterns that indicated either a bi-directional or unidirectional exposure-response relationship were selected for more detailed analyses in Stage 3.

3.2.3 Stage 3

This stage explored both individual measurement quintiles as well as quintiles for summary statistics derived from all measurements collected. Summary statistics included the maximum, minimum, range, median, interquartile range, and standard deviation of all climate measurements for each participant. We also derived the average wake up and bedtime measurements on the weekday and weekend day. The values of these new variables were derived only if five out of the eight TUD measurements were non-missing data.

For each derived quintile-based variable we used logistic regression analyses to determine if the upper or lower temperature quintiles differed from the middle temperature quintile (reference) in terms of the odds of experiencing each child health outcome. In all logistic regression models in this stage, odds ratios were adjusted for season (summer, autumn, winter, spring) and individual household deprivation (NZiDep index). NZiDep was calculated from existing information collected as part of the GUiNZ DCW when the children were 54-months of age.

We selected adjusted associations with bi-directional or unidirectional exposure-response patterns. Among all selected associations, we chose an optimal model based on Maddala R^2 statistics ($\boldsymbol{M}$) (Lai *et al.* 2020), a pseudo-R^2, which allows comparison of goodness-of-fit across similar models in different sample sizes without quantifying the proportion of variation explained by the independent variables (Allison 1995; Veall and Zimmermann 1996):

$$\boldsymbol{M} = 1 - e^{-(\frac{L}{n})}$$

Where L is the difference in -2log likelihood for the null model without a covariate and the fitted model with covariate(s), n is the sample size. The optimal model chosen formed a basis for selecting the most sensitive outcome and indoor measures for the final two stages of data analyses.

3.2.4 Stage 4

To determine the optimal range of either the temperature or Humidex for each measurement these measures were divided into three groups, a middle range representing the optimal temperature or Humidex and lower and upper ranges representing a potentially adverse climate. For each derived variable we used logistic regression analyses to determine if the upper or lower ranges differed from the optimal range (as reference) in terms of the odds of experiencing each child health outcome. In all logistic regression models, odds ratios were adjusted for season (summer, autumn, winter, spring) and individual household deprivation (NZiDep index).

We hypothesised that child health impacts would likely be observable when the indoor climate was below the lower, or above the upper limit (using indoor climate between the two limits as a reference). To evaluate the stability of the exposure-response relationships that had been observed, we chose an optimal model (based on Maddala R^2 statistics) from a matrix of models where each optimal range varied in the lower or the upper limit value by one unit. The range of the lower and upper limit value included in the search of an optimal model began from the values in the lowest and highest deciles of the indoor measure.

We then determined the optimal range for both temperature and Humidex. We began the search for an optimal model using the lower temperature limit and the upper Humidex limit from the two optimal models selected.

3.2.5 Stage 5

This stage provided information about the sociodemographic factors that were associated with indoor climate being outside the optimal cut-off points - as identified in Stage 4.

We used logistic regression to assess the associations between the likelihood of having poorer indoor climate (as a binary variable) and the 25 sociodemographic factors (as binary, nominal or ordinal variables) that described the home environment, material deprivation, housing and finance, parenting time and support, maternal health and wellbeing, and demographic information of the children. All these associations were adjusted for season of environmental measurement.

We selected potential associations ($P<0.05$) based on Wald Chi-square tests of the effect and then plotted the odds ratios of these associations for visual examination and further interpretation of the observed patterns.

4 Results

This study was conducted in New Zealand, which has a climate that varies from warm subtropical in the far north to cool temperatures in the far south. However, the study participants in the *GUiNZ* cohort study were recruited initially only from pregnant mothers who were residing in the greater Auckland and Waikato regions (Morton *et al.* 2010) where the climate zone is categorised as subtropical/temperate. While by the eight-year DCW, many families have moved and they are now reside from the far north to far south of the country (see Appendix A) the majority still reside in the original recruitment areas. Therefore, it may not be possible to extrapolate or generalise the results of this study to parts of the country that regularly experience colder or more extreme temperatures. For this reason, it is possible that the associations between indoor temperatures and child wellbeing reported in this study may be an underestimate of the association seen for all regions.

4.1 Participation and completion rates

Overall, 81% of eligible baseline cohort children (n=6853) took part in some component of the 8-year DCW (Morton *et al.* 2020). However, 19% did not participate in any part of the eight-year DCW (n=1297) and a further 11% did not participate in the Time Use Diary component (TUD) (n=735). Of the remainder (70%) that agreed to take part in completing the TUDs (n=4808), almost half of the TUDs were returned to the research team (48%; n=2315). Of those children that returned their TUDs, 96% had completed at least one section of the temperature and relative humidity sections; excluding the ones on the practise page which were undertaken with the interviewer (n=2232). The measures from the practise page were excluded as the completion rates could have been affected by interviewer bias. A breakdown of TUD completion rates by a variety of baseline and 8-year sociodemographic variables are presented in Table 3.

Table 3. Summary statistics of completion rates for 8-year DCW.

	TUD returned with T and RH (n=2232)		TUD given but not returned (n=2589)		Did not complete 8Y (n=1297)		Completed 8Y but not TUD (n=735)	
	n	%	n	%	n	%	n	%
Child gender (8-year DCW)								
Male	1092	49%	1356	52%	680	52%	404	55%
Female	1140	51%	1233	48%	617	48%	331	45%
Mother age group (antenatal DCW)								
< 20 years	20	1%	141	5%	140	11%	26	4%
20-24 years	170	8%	390	15%	322	25%	113	15%
25-29 years	467	21%	656	25%	337	26%	212	29%
30-34 years	876	39%	760	29%	282	22%	209	28%
35-39 years	584	26%	536	21%	173	13%	146	20%
40+ years	115	5%	105	4%	43	3%	29	4%
Missing information	<10	<1%	<10	<1%	<10	<1%	<10	<1%
Mother education (antenatal DCW)								
No secondary school qualification	49	2%	184	7%	195	15%	61	8%
Secondary school/NCEA 1-4	370	17%	642	25%	438	34%	177	24%
Diploma/ Trade certificate/ NCEA 5-6	580	26%	850	33%	429	33%	236	32%
Bachelor's degree	709	32%	561	22%	143	11%	139	19%
Higher degree	523	23%	344	13%	85	7%	118	16%
Missing information	<10	<1%	<10	<1%	<10	1%	<10	1%

Table 3 (continued).

	TUD returned with T and RH (n=2232)		TUD given but not returned (n=2589)		Did not complete 8Y (n=1297)		Completed 8Y but not TUD (n=735)	
	n	%	n	%	n	%	n	%
Child self-identified ethnicity (8-year DCW)								
NZ European	1234	55%	1061	41%			51	7%
Māori	257	12%	493	19%			34	5%
Pacific	115	5%	359	14%			39	5%
Asian	205	9%	225	9%			9	1%
Other	67	3%	91	4%			4	1%
I don't think about it	334	15%	335	13%			14	2%
Missing information	20	1%	25	1%	1297	100%	584	79%
NZDep2006 (antenatal DCW)								
1	247	11%	196	8%	41	3%	38	5%
2	250	11%	211	8%	62	5%	63	9%
3	230	10%	251	10%	54	4%	65	9%
4	265	12%	261	10%	64	5%	55	7%
5	221	10%	191	7%	61	5%	56	8%
6	231	10%	257	10%	91	7%	68	9%
7	238	11%	260	10%	115	9%	71	10%
8	203	9%	289	11%	181	14%	80	11%
9	204	9%	337	13%	251	19%	103	14%
10	143	6%	334	13%	377	29%	135	18%
Missing information	<10	<1%	<10	<1%	<10	<1%	<10	<1%

Table 3 (continued).

	TUD returned with T and RH (n=2232)		TUD given but not returned (n=2589)		Did not complete 8Y (n=1297)		Completed 8Y but not TUD (n=735)	
	n	%	n	%	n	%	n	%
Household income (antenatal DCW)								
<=20K	27	1%	77	3%	92	7%	24	3%
>20K <=30K	51	2%	107	4%	90	7%	43	6%
>30K <=50K	190	9%	261	10%	187	14%	93	13%
>50K <=70K	237	11%	362	14%	169	13%	93	13%
>70K <=100K	473	21%	470	18%	151	12%	119	16%
>100K <=150K	523	23%	438	17%	97	7%	104	14%
>150K	366	16%	271	10%	40	3%	76	10%
Missing information	565	25%	603	23%	471	36%	183	25%
Household income (8-year DCW)								
<=30K	92	4%	188	7%			40	5%
>30K <=70K	319	14%	491	19%			76	10%
>70K <=150K	877	39%	816	32%			108	15%
>150K	692	31%	479	19%			65	9%
Missing Information	252	11%	615	24%	1297	100%	446	61%
Partner/Spouse (mother antenatal DCW)								
Yes	1991	89%	2199	85%	1052	81%	613	83%
No	52	2%	138	5%	100	8%	46	6%
Don't Know/ Missing information	189	8%	252	10%	145	11%	76	10%

Table 3 (continued).

	TUD returned with T and RH (n=2232)		TUD given but not returned (n=2589)		Did not complete 8Y (n=1297)		Completed 8Y but not TUD (n=735)	
	n	%	n	%	n	%	n	%
Household structure (8-year DCW)								
Parent alone	174	8%	263	10%			66	9%
Two parents	1695	76%	1672	65%			304	41%
Parent(s) with extended family	242	11%	498	19%			106	14%
Parent(s) living with non-kin (and extended family if applicable)	107	5%	112	4%			15	2%
Missing information	14	1%	44	2%	1297	100%	244	33%
Household tenure (8-year DCW)								
Own	1662	74%	1391	54%			163	22%
Private rental	397	18%	622	24%			134	18%
Public rental	41	2%	172	7%			28	4%
Other	78	3%	158	6%			37	5%
Missing	54	2%	246	10%	1297	100%	373	51%
Full or part ownership of house (antenatal DCW)								
Yes	1277	57%	1184	46%	330	25%	285	39%
No	768	34%	1157	45%	818	63%	374	51%
Don't Know/ Missing information	187	8%	248	10%	149	11%	76	10%

In summary, a similar proportion of male and female children completed the TUD compared to those that did not. However, the pattern of completion was different for children of different self-identified ethnicities, with a higher proportion of NZ European children completing the TUD compared to those that did not, but a higher proportion of Māori and Pacific children that did not complete the TUD as compared to those that did. The proportion was the same for self-identified Asian children. In general, a lower proportion of children completed the TUD if their mother was less than 30 years old when they were born, or whose education qualifications were less than a Bachelor's degree at the time of the antenatal interview. This trend was also observed for children whose mothers at the antenatal interview were living in high deprivation areas (8-10 which are most deprived) or mothers who reported their family income as being less than $70K per annum at the 8-year DCW. A higher proportion of children completed the TUD in two parent families compared to other family situations and a higher proportion of children completed the TUD if at the 8-year DCW the mother reported they lived in a home that was owned as compared to a rental home or other tenure type. This table demonstrates that there is bias in the group of children who completed the TUD and returned them to the *GUiNZ* team. The results reflect results from children who are generally experiencing less deprivation and less vulnerability according to the measured family socio-demographics. This may mean that the findings in this report underestimate the full impact that indoor housing conditions are having on child health and wellbeing within New Zealand.

4.2 Stage 1: Descriptive analyses of indoor climate

The mean indoor temperature (°C) of the six TUD measurements at home was 20.2 (range: 10.3 to 29.5, SD=2.80, n=2199). The mean indoor temperature of the two TUD measurements at school was 20.2 (4.0 to 34.6, SD=3.33, n=1930). The corresponding mean values of NIWA outdoor temperatures, measured in the local area, were 13.4 for home (-1.7 to 24.5, SD=3.87, n=2217) and 14.9 for school (-0.8 to 30.9, SD=4.31, n=2023). The wake-up (mean 18.5°C) and bedtime (mean 21.1°C) temperatures were similar for weekday and weekend measurements. The mean school indoor temperature in the morning and at lunch were 18.9°C and 21.4°C, respectively. The mean, median and other summary statistics of all indoor measurements before and after removal of outliers are shown in Appendix C.

4.2.1 Correlation of indoor and outdoor temperature

Overall, indoor temperature measurements were highly positively correlated with the outdoor temperatures obtained from linkage to routine NIWA records. These are presented in Figure 2 for each indoor measurement timepoint. Note the slope for each of the correlations is also similar for each timepoint regardless of day or time.

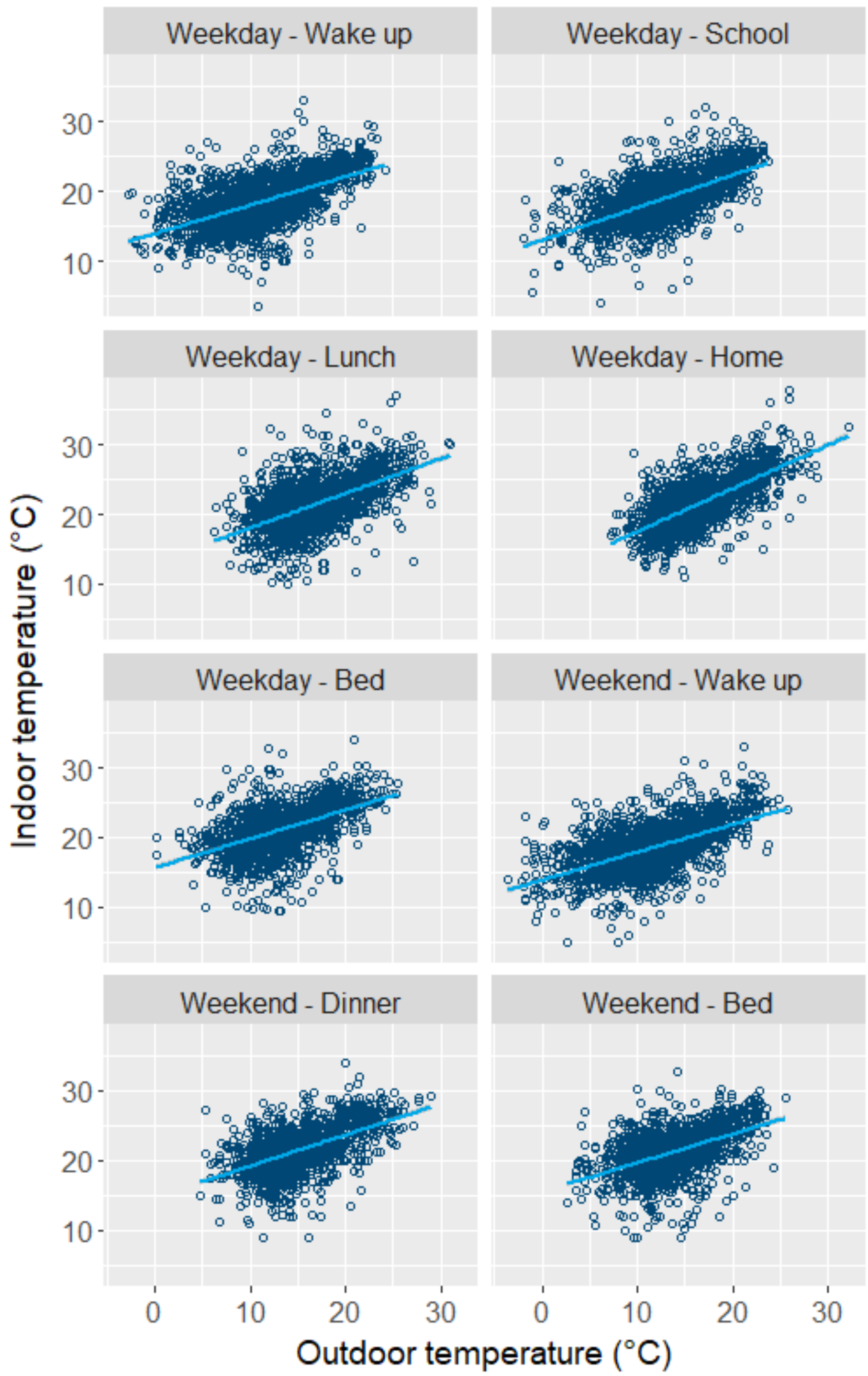


Figure 2. Correlation between Indoor temperature and outdoor temperature as recorded at the local NIWA weather station

4.2.1 Distribution of indoor temperature

Distributions of temperature measurements at each time point are shown in Figure 3, and the description of quintiles used for subsequent analyses are presented in Table 4.

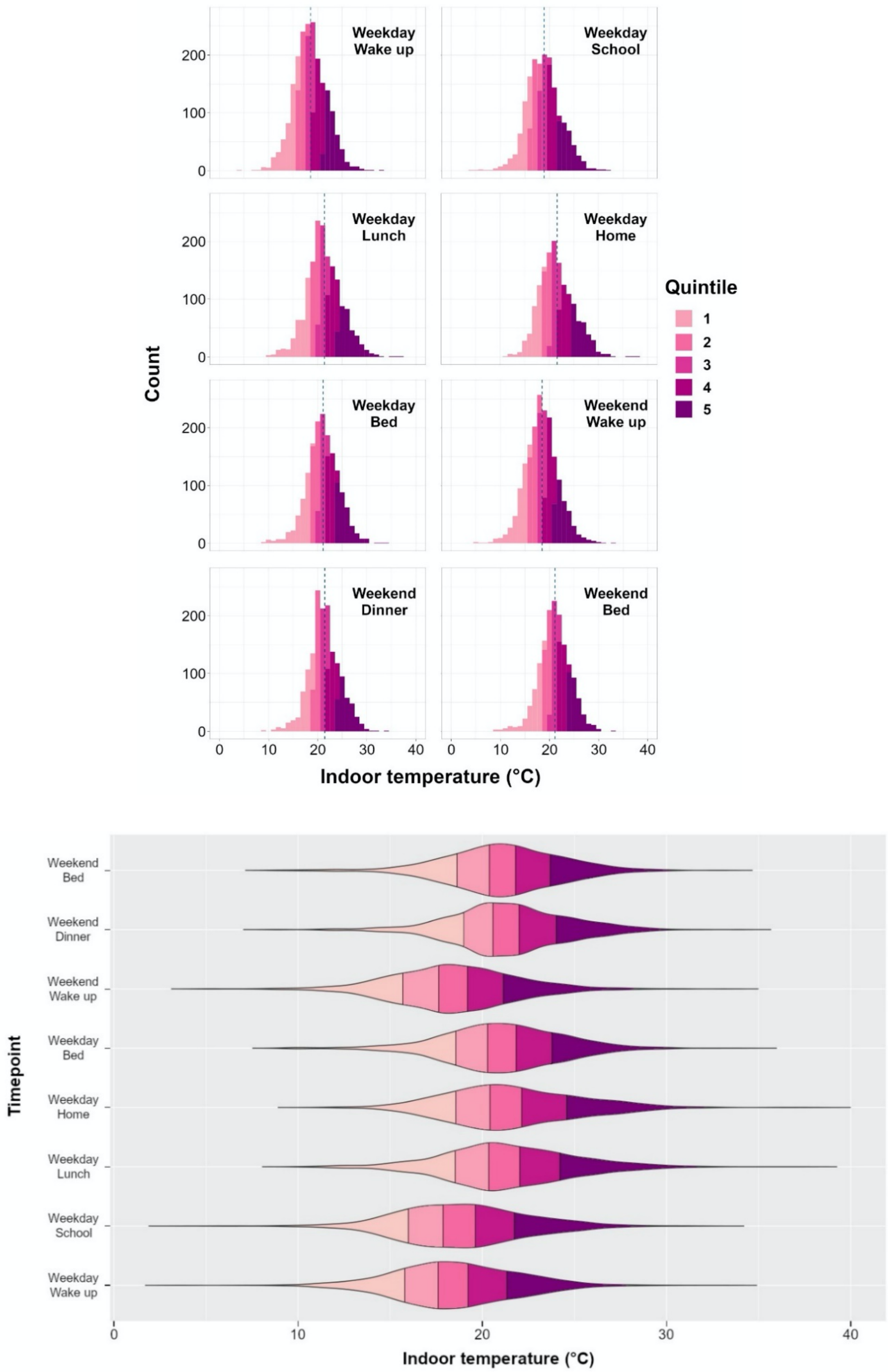


Figure 3. Distribution of time and temperature recordings

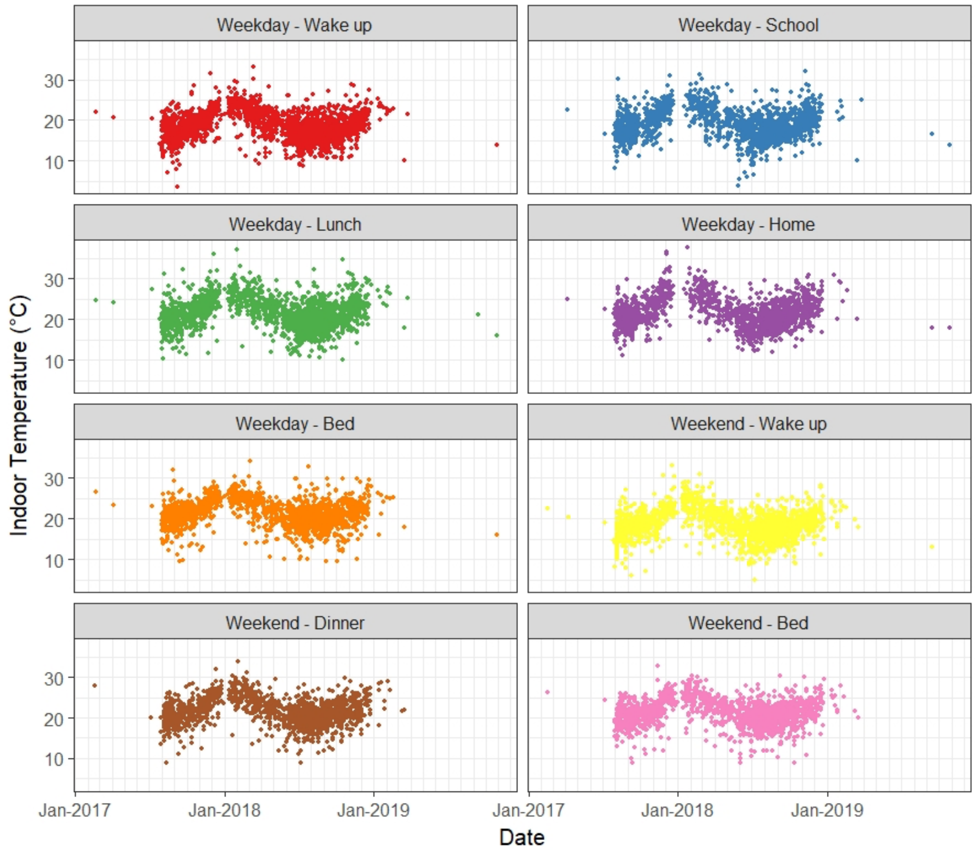
Table 4. Temperature range for quintiles for each measurement.

Measurement	Quintile temperature range				
	1	2	3	4	5
Weekday - Wake up	3.6°C – 15.9°C	16°C – 17.6°C	17.7°C – 19.1°C	19.2°C – 21.3°C	21.4°C - 33°C
Weekday - School	4°C – 16.1°C	16.2°C – 17.8°C	17.9°C – 19.6°C	19.7°C – 21.6°C	21.7°C – 32.1°C
Weekday - Lunch	10.1°C – 18.5°C	18.6°C – 20.3°C	20.4°C - 22°C	22.1°C – 24.1°C	24.2°C – 37.2°C
Weekday - Home	11.1°C – 18.6°C	18.7°C – 20.4°C	20.5°C - 22°C	22.1°C – 24.5°C	24.6°C – 37.8
Weekday - Bed	9.4°C – 18.6°C	18.7°C – 20.2°C	20.3°C – 21.8°C	21.9°C – 23.8°C	23.9°C – 34.1°C
Weekend - Wake up	5°C – 15.7°C	15.8°C – 17.7°C	17.8°C – 19.1°C	19.2°C – 21.1°C	21.2°C – 33.1°C
Weekend - Dinner	8.8°C – 19°C	19.1°C – 20.5°C	20.6°C – 22°C	22.1°C – 24°C	24.1°C – 33.9°C
Weekend - Bed	9.4°C – 18.6°C	18.7°C – 20.2°C	20.3°C – 21.8°C	21.9°C – 23.8°C	23.9°C – 34.1°C

Table 3 and Table 4 illustrate an increase in temperatures across the day for both weekday and weekend measurements. Quintiles are also similar for both weekday and weekend temperatures. Additionally, the temperature ranges for school and home were similar. The minimum temperature recorded was 3.6˚C at wake up on a weekday and the maximum recorded temperature was 37.8˚C recorded on a weekday at home.

4.2.2 Seasonal variation of indoor temperature and humidity

There was a seasonal pattern in indoor temperature measurements from 2017 to 2019, with lower median temperatures in the winter months and higher temperatures in the summer months as we would expect (Figure 4). However, we did not observe any obvious seasonal pattern in indoor relative humidity measurements (Figure 4). On winter weekdays, the wake-up (mean 17.1°C) and bedtime (mean 20.0°C) indoor temperatures were about 5°C lower than those in summer (wake-up: 22.6°C, bedtime: 24.7°C). Similarly, in winter, the school indoor temperatures in the morning (mean 17.2°C) and at lunch time (mean 19.7°C) were 5-6°C lower than those in summer (morning: 23.2°C, lunch: 25.3°C). We also observed a diurnal pattern with generally lower temperature in the wake up time and higher temperatures after returning home from school. Indoor relative humidity tended to be lower in spring (Figure 4).



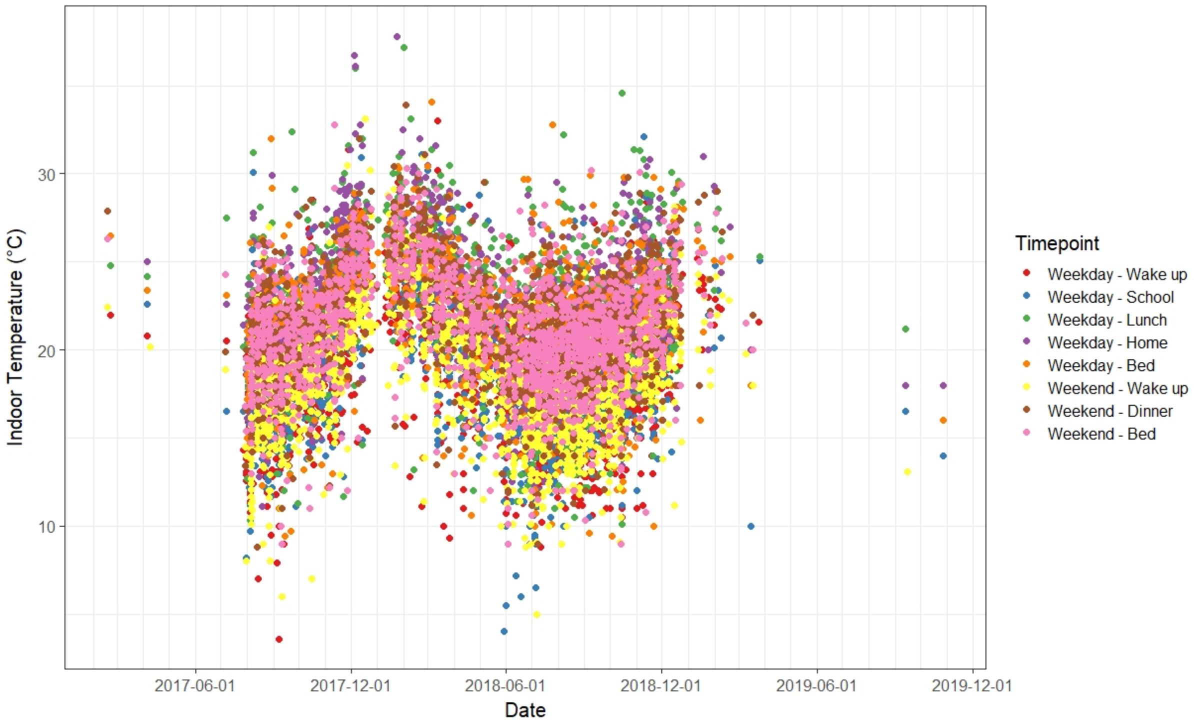
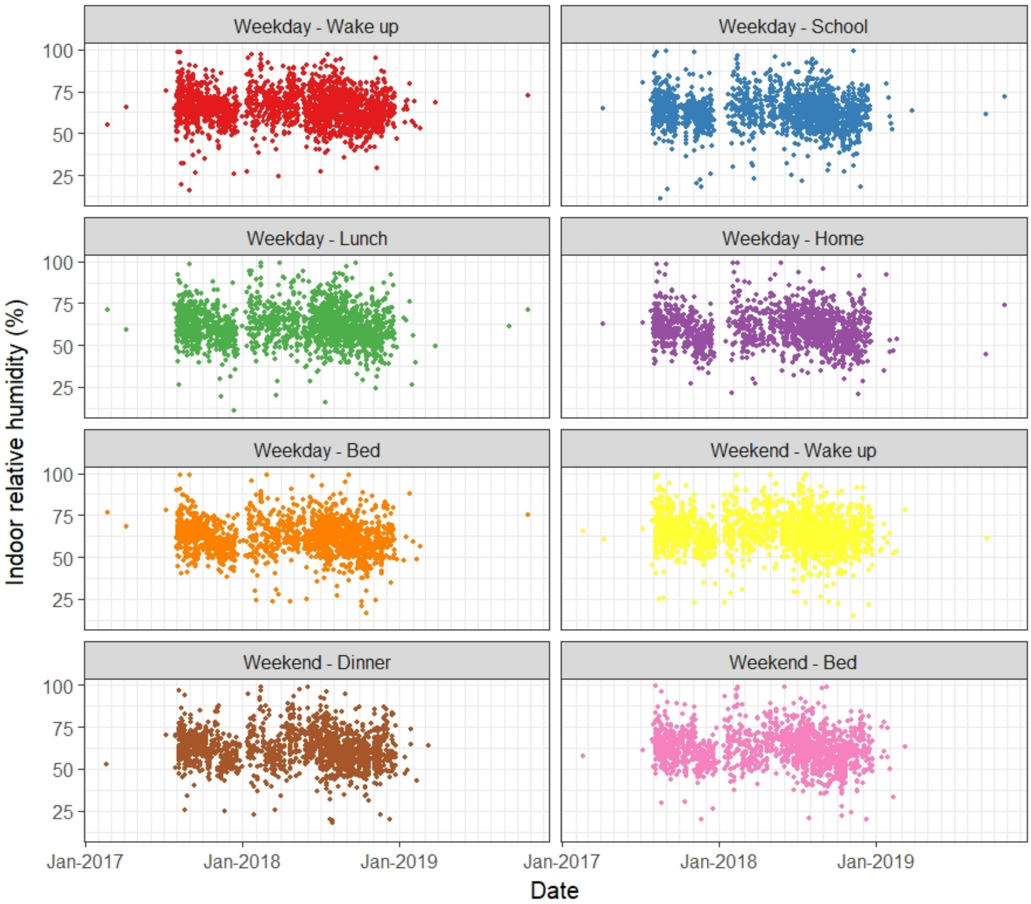


Figure 4. Indoor temperature and humidity variation across the DCW period



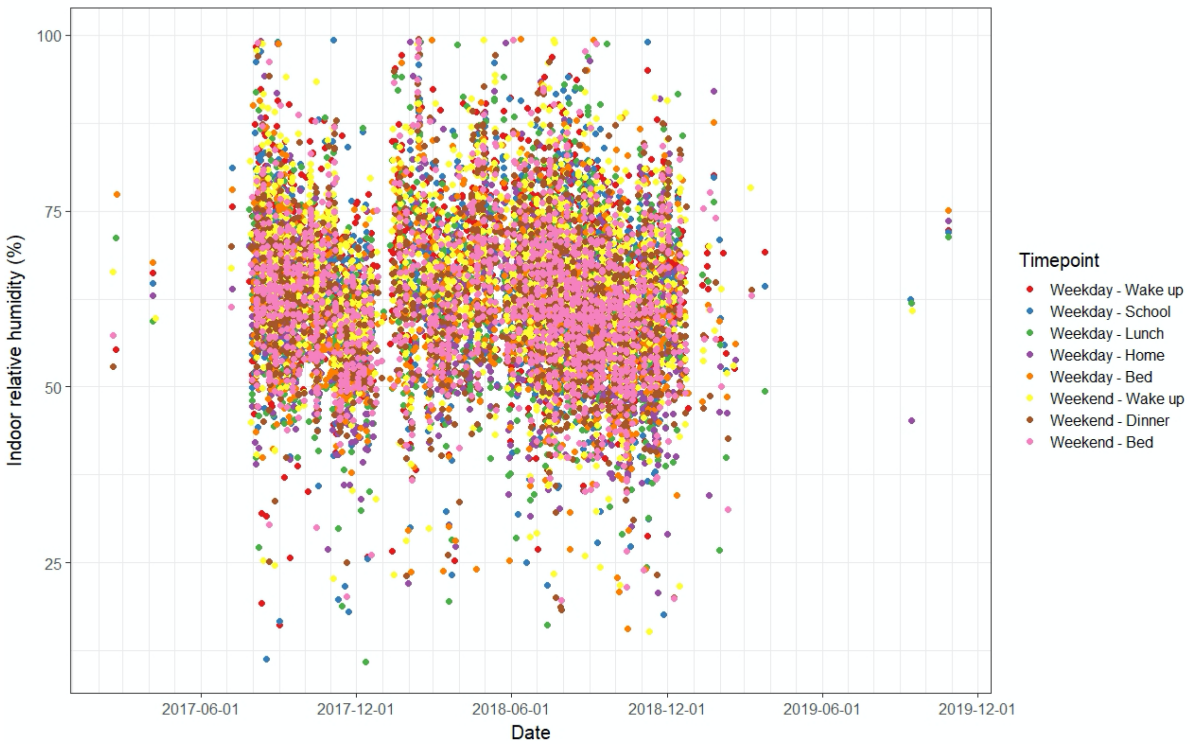


Figure 4 (continued). Indoor temperature and humidity variation across the DCW period

4.3 Stage 2: Identify sensitive outcomes (health and wellbeing) from the patterns of associations with indoor climate measures across the 8 TUD periods

The results of the Chi-Square test between the 20 health and wellbeing outcomes (binary variables) and the eight indoor temperature measurements (quintiles) are presented in Table 5. Overall, there was a significant difference in proportions (P<0.05) for at least one temperature measurement for nine of the 20 health outcomes. These outcomes included non-food allergies, ear infections, asthma, cough (lasting > 4 weeks), throat infection/tonsillitis, respiratory illnesses, antibiotics used for respiratory illnesses, higher depression score, highest decile in anxiety score, and suboptimal/poorer general health. For four of the health outcomes (ear infections, asthma, highest decile anxiety score and suboptimal/poorer general health), more than one temperature measurement was significantly associated with the outcome.

Table 5. Crosstab analyses of the associations between 20 outcomes and 8 indoor temperature measurements.

Health and wellbeing outcomes	Indoor temperature (in quintiles)							
	Weekday					Weekend		
	Wake up	School	Lunch	Home	Bed	Wake up	Dinner	Bed
Non-food allergies (Ref: no)								<0.05
Hay-fever (Ref: no)								
Ear infections (Ref: no)		<0.05		<0.05				
Asthma (Ref: no)		<0.01						<0.05
Whooping cough or pertussis (Ref: no)								
Other respiratory disorders (Ref: no)								
Cough lasting > 4 weeks (Ref: no)			<0.05					
Wheezing in the chest (Ref: no)								
Gastroenteritis (Ref: no)								
Eczema or dermatitis (Ref: no)								
Throat infection or tonsillitis (Ref: no)						<0.05		
Skin infections (Ref: no)								
Respiratory illnesses (Ref: no)								
Antibiotics for respiratory (Ref: no)	<0.05							
Higher depression score (Ref: <10)		<0.05						
Higher anxiety score (Ref: <65)								
Highest decile in depression score (Ref:<13)								
Highest decile in anxiety score (Ref: <61)	<0.05		<0.05	<0.05				
Suboptimal or poorer general health*			<0.05		<0.001			
Poorer general health**								

*Ref: Excellent/Very Good; **Ref: Excellent/Very Good/Good

Chi-Square P-value: (black) <0.001 (dark grey) <0.01 (light grey) <0.05

Among the 14 statistically significant associations identified, three had a bidirectional or unidirectional exposure-response pattern in the logistic regression analyses using the middle quintile temperature as the reference. These three outcomes were: suboptimal/poorer general health, higher depression score, and highest decile in anxiety score Figure 5. Crude odds ratios (95CI) between health and wellbeing outcomes (binary) and indoor temperature quintile (Q)(Figure 5). The other 11 associations did not have a bidirectional or unidirectional exposure-response pattern. Note 'Poor general health' in Figure 5 refers to the suboptimal/poorer general health outcome measure.

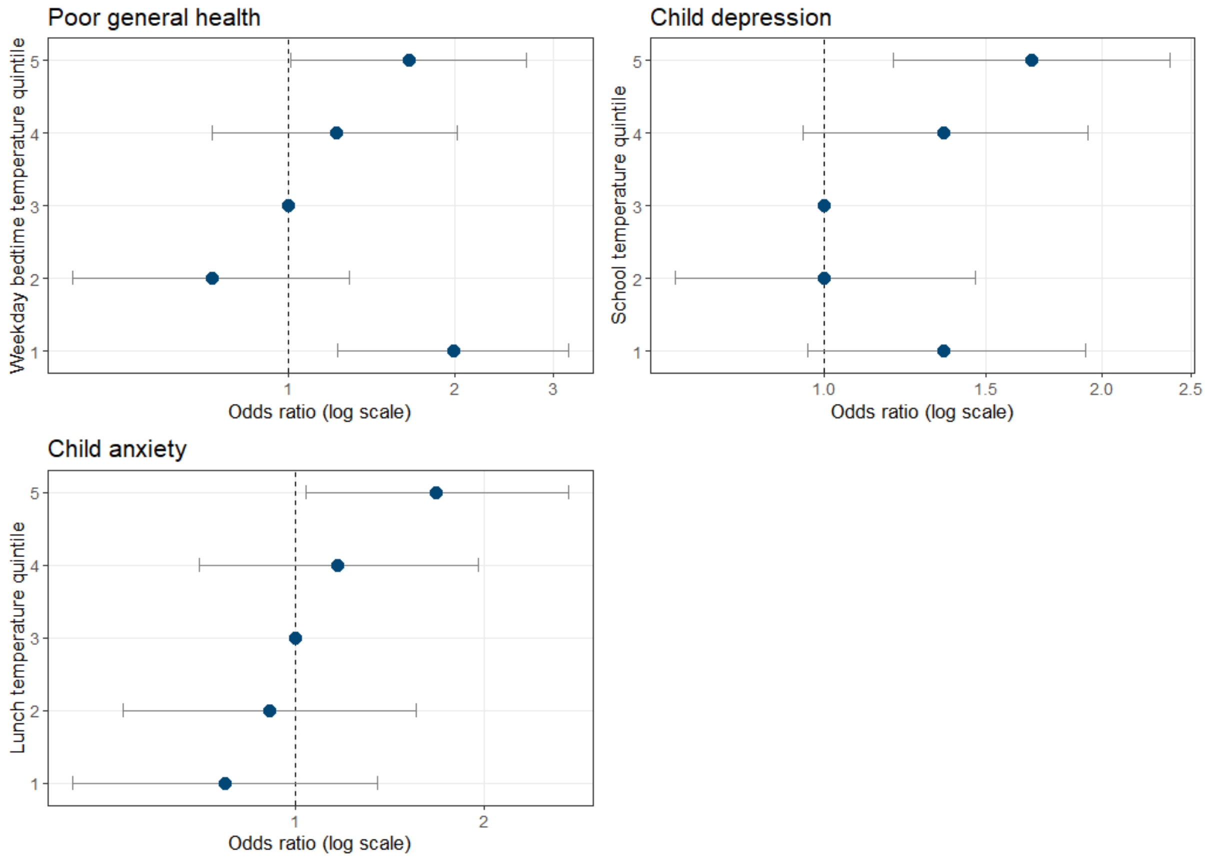


Figure 5. Crude odds ratios (95CI) between health and wellbeing outcomes (binary) and indoor temperature quintile (Q)

[Note: **Odds ratios** (OR) are used throughout this report as they provide a useful measure of the association between an exposure and an outcome. Specifically the OR represents the **odds** that an outcome will occur given a particular exposure, compared to the **odds** of the outcome occurring in the absence of that exposure. For example, the first plot of Figure 5 (outcome of poorer general health) provides evidence for **increased odds** of poorer general health at lower bedtime temperatures (quintile 1) compared to children with higher bedtime temperatures (quintile 3).]

4.4 Stage 3: Identify sensitive indoor climate measures (among 8 TUD periods and the 8 derived statistics) from patterns of adjusted associations with the selected outcomes

An additional eight summary statistics derived from the original eight indoor measurements were added to the assessment of associations with the three identified outcomes from Stage 2. Among all the logistic regression analyses between the three outcome variables and the 16 indoor temperature variables, we identified six bidirectional exposure-response associations. Among these six logistic regression models, an association between suboptimal/poorer general health and weekday bedtime indoor temperature appeared as having the highest model fit statistic (M=311.8) and the most prominent pattern of bidirectional exposure-response relationship (Figure 6). Note 'Poor general health' in Figure 6 refers to the suboptimal/poorer general health outcome measure.

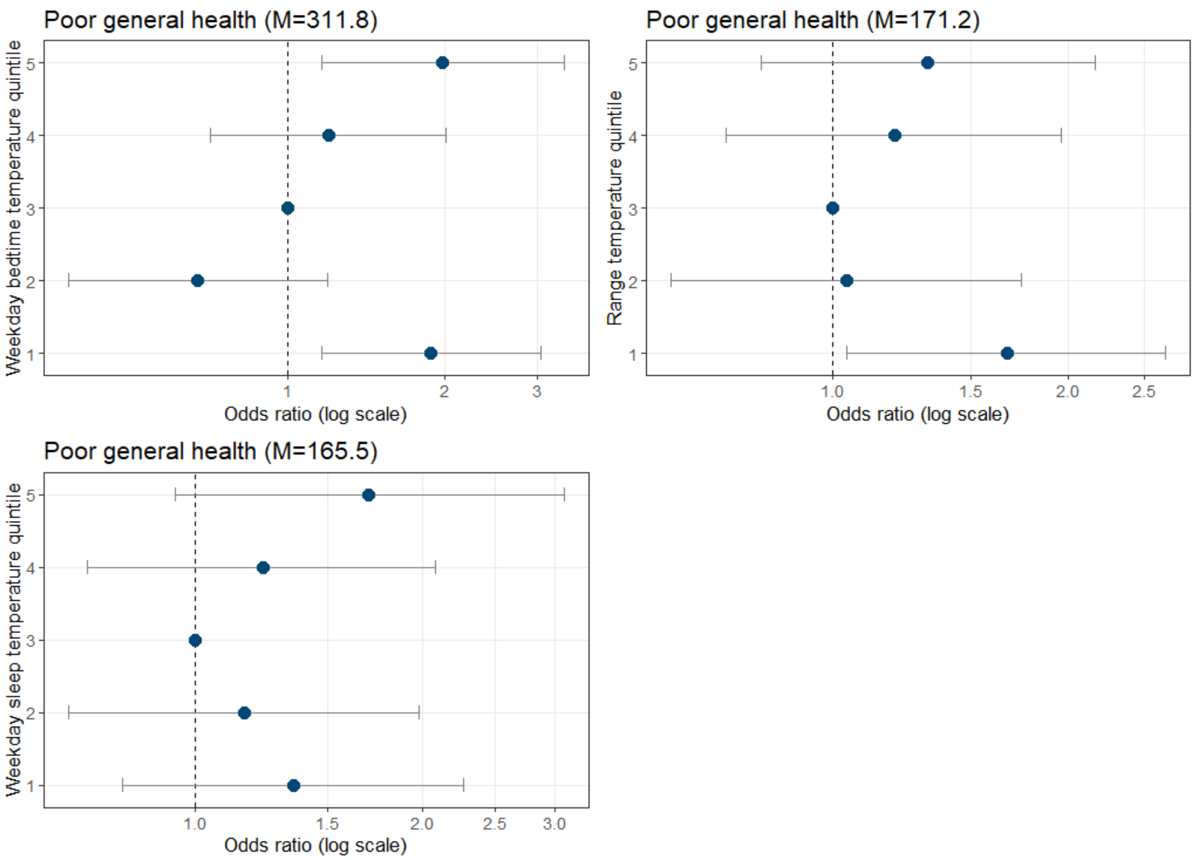


Figure 6. Adjusted odds ratios (95CI) between suboptimal/poorer general health and indoor temperature quintile (Q)

We also found an association between the two wellbeing outcomes and the suboptimal/poorer general health outcome in the logistic regression models. The adjusted odds ratios (95% CI) of having suboptimal/poorer general health was 1.020 (1.007, 1.033) per one anxiety score increase and was 1.042 (1.014, 1.071) per one depression score point increase (Figure 7 and Figure 8).

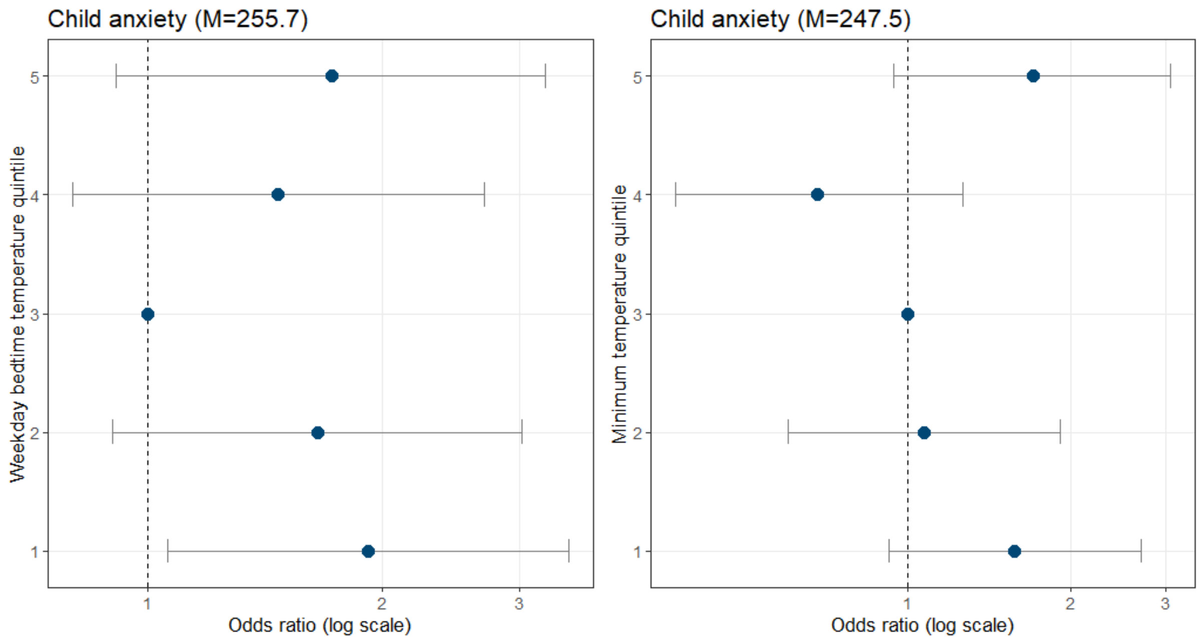


Figure 7. Adjusted odds ratios (95CI) between highest decile in anxiety score (over past 7 days) and indoor temperature quintile (Q)

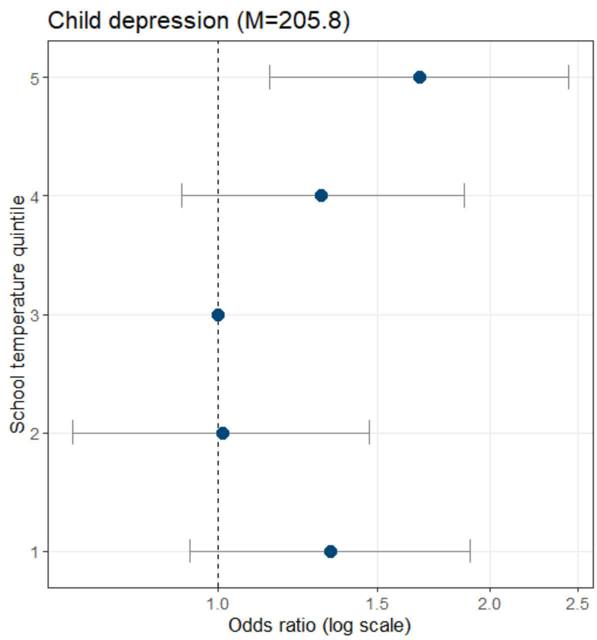


Figure 8. Adjusted odds ratios (95CI) between higher depression score (7 days) and indoor temperature quintile (Q)

Based on the highest model fit statistics, we found the most obvious bidirectional exposure-response relationship existed between the weekday bedtime indoor temperature and the suboptimal/poorer general health outcome.

4.5 Stage 4: Find cut-off points to describe an optimal range of healthier indoor climates for children

Given the findings above, analyses from stage 4 onwards focus on **weekday bedtime** indoor temperature measures and **poor/suboptimal general health** outcomes only.

4.5.1 Indoor temperature and child general health

The model statistics for determining the optimal temperature range variable for weekday bedtime temperature and child general health are presented in Table 6. The bedtime temperature variable with the highest model fit statistic for detecting the effect of temperature on general health had an optimal range between 19 and 25°C. In this model, children who experienced bedtime temperatures less than 19°C or greater than 25°C had increased odds of experiencing suboptimal/poorer general health (Figure 9). Note 'Poor general health' in Figure 9 refers to the suboptimal/poorer general health outcome measure.

Table 6. Determining the cut-off points of indoor bedtime temperature.

Model statistics		Higher cut-off limit					
		>23°C	>24°C	**>25°C**	>26°C	>27°C	>28°C
Lower cut-off limit	<16°C	189.9	222.6	232.1	181.3	188.6	181.1
	<17°C	191.9	224.9	234.0	182.6	189.8	182.2
	<18°C	260.1	294.2	297.9	239.2	246.4	237.8
	<19°C	269.8	303.7	**303.9**	241.3	248.4	239.2
	<20°C	194.2	228.1	234.9	181.2	188.4	180.7
	<21°C	187.4	221.0	229.2	179.4	186.6	179.5

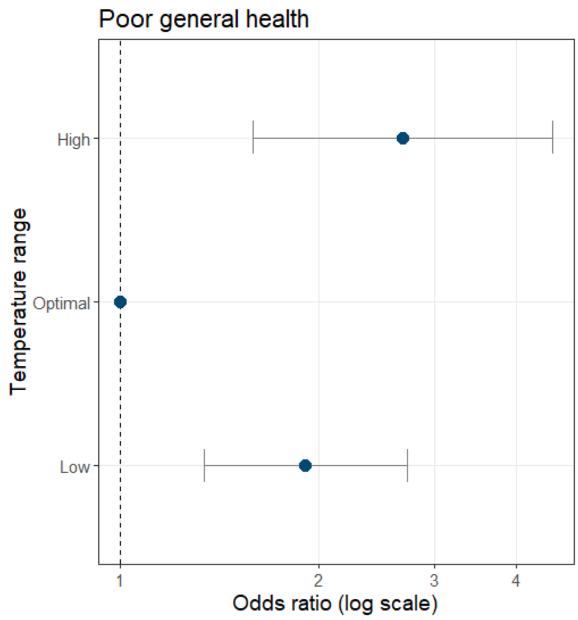


Figure 9. Adjusted odds ratios (95CI) between suboptimal/poorer general health (same day) and the selected indoor bedtime temperature cut-off limits

Based on the model with the highest model fit statistics, we found adverse effects on general child health when the indoor weekday bedtime temperature was lower than 19°C (odds ratio [95CI]: 1.91 [1.34-2.73]) and higher than 25°C (2.69 [1.59-4.53]).

4.5.1 Indoor Humidex and child general health

The model statistics for determining the optimal Humidex range variable for the weekday bedtime measurements and child general health are presented in Table 7. The bedtime Humidex variable with the highest model fit statistic for detecting the effect of Humidex on general health had an optimal range between 21 and 28. In this model, children who experienced bedtime Humidex measures of less than 21 or greater than 28 had increased odds of experiencing suboptimal/poorer general health (Figure 10) (Appendix F).

[Note: Caution should be given when interpreting the lower cut-off limit of Humidex, which was designed for assessing heat stress rather than cold stress (Masterton and Richardson 1979)]

Table 7. Determining the cut-off points of indoor bedtime Humidex.

Model statistics		Higher cut-off limit					
		>26	>27	**>28**	>29	>30	>31
Lower cut-off limit	<18	203.7	218.5	227.3	200.6	205.7	179.6
	<19	210.1	224.8	233.1	205.0	209.9	183.1
	<20	213.1	227.5	235.3	205.9	210.5	183.2
	<21	237.2	249.9	**255.1**	220.8	224.3	194.8
	<22	227.5	239.5	244.3	210.2	213.8	184.8
	<23	220.6	232.0	236.3	202.1	205.9	177.5

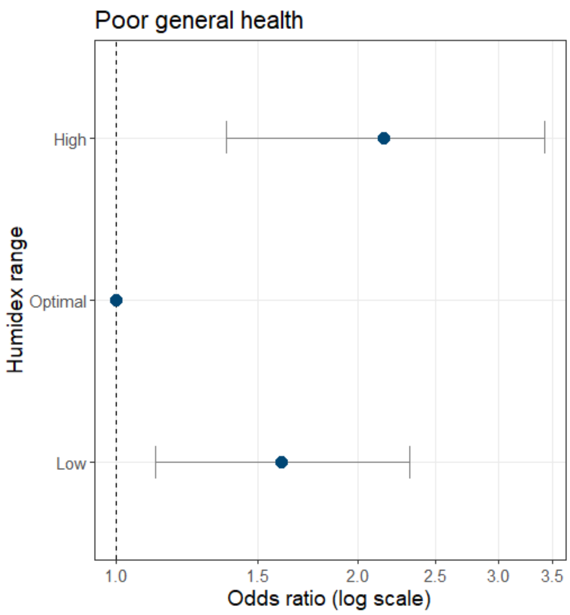


Figure 10. Adjusted odds ratios (95CI) between suboptimal/poorer general health (same day) and the selected indoor bedtime Humidex cut-off limits

Based on the model with the highest model fit statistics, we found adverse effects on general health in children when Humidex was lower than 21 (odds ratio [95CI]: 1.61 [1.12-2.32]) and higher than 28 (2.16 [1.37-3.42]).

4.5.2 Combined indoor temperature and Humidex and child general health

The model statistics for determining the optimal combination of temperature and Humidex range for the weekday bedtime measurements and child general health are presented in Table 8. The variable with the highest model fit statistic for detecting the effect of climate (as determined by temperature and Humidex) on general health used a minimum temperature of 19°C and a maximum Humidex of 28. In this model, children who experienced bedtime temperatures less than 19°C or a Humidex value greater than 28 had increased odds of experiencing suboptimal/poorer general health (Figure 11Figure) (Appendix F).

Table 8. Determining the combined cut-off points of indoor bedtime Temperature-Humidex.

Model statistics		Higher cut-off limit (Humidex)						
		>25	>26	>27	**>28**	>29	>30	>31
Lower cut-off limit (Temperature)	<17°C	172.9	180.8	188.2	192.5	177.4	180.7	166.6
	<18°C	212.4	221.6	228.1	230.4	208.8	211.1	192.1
	<19°C	228.3	236.5	241.3	**241.7**	216.9	218.4	197.8
	<20°C	na	182.1	190.9	193.9	176.5	179.5	164.9
	<21°C	na	na	na	184.7	169.2	172.4	160.0
	<22°C	na	na	na	na	167.2	170.1	162.4

'na' indicates a model not available due to situation(s) that can satisfy both limits at the same time

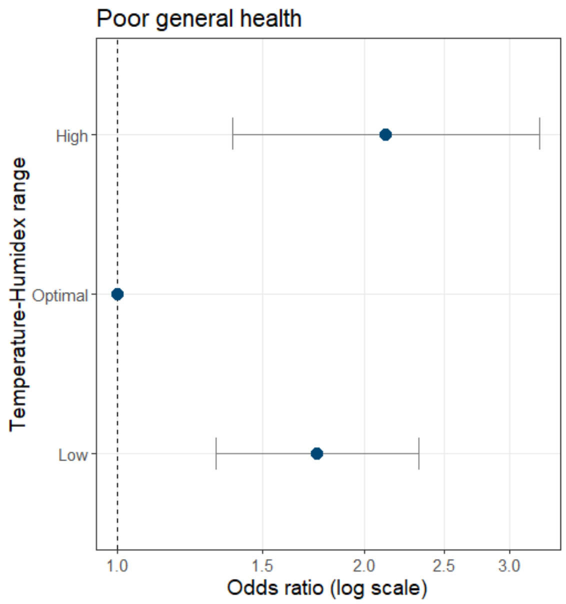


Figure 11. Adjusted odds ratios (95CI) between suboptimal/poorer general health (same day) and the selected indoor bedtime Temperature-Humidex cut-off limits

Based on the model with the highest model fit statistics, we found adverse effects on general health in children when temperature was lower than 19°C (odds ratio [95CI]: 1.75 [1.32-2.33]) and Humidex higher than 28 (2.12 [1.38-3.26]).

4.6 Stage 5: Assessment of sociodemographic factors related to indoor climate being outside the optimal range

4.6.1 Sociodemographic variables associated with indoor climate

Indoor climate measures were found to be associated with child and family sociodemographic characteristics. Specifically, the likelihood of participants experiencing non-optimal climate conditions (defined as temperature less than 19°C and Humidex greater than 28) was associated with metrics related to the home environment, material deprivation, housing and finances, parenting support, maternal health and wellbeing, and child's ethnicity (Table 9Table 7).

Table 9. Logistic regression analyses of associations between sociodemographic factors and weekday indoor bedtime climate being outside the optimal range (between 19°C and 28 Humidex).

Sociodemographic factors measured in eight-year DCW		**Wald Chi-Square**
Home environment	Number of people living in the house	**0.003**
	Number of bedrooms in the house	**0.004**
	Household crowding (people per bedroom)	**<0.001**
	Non-bedroom areas for regular sleeping	**0.002**
	Home environment is like a "zoo"	0.241
	Put up with feeling cold to reduce cost	**<0.001**
	House problem: dampness or mould	**0.002**
	House problem: heating / keep warm in winter	**<0.001**
Material deprivation	Household affordability to eat properly	**0.007**
	Household food runs out due to lack of money	**0.001**
	Material Wellbeing Index percentile rank*	**<0.001**
	Dep-17 Material Hardship Index	**<0.001**
Housing and finance	Owning or partly owning the house/flat	**<0.001**
	Paying rent / mortgage for the house/flat	**0.001**
	Household income total (before tax)	**<0.001**
	Household debt total (excl. mortgage / home loan)	0.269
Parenting time and support	Mother's working hours per week	0.311
	Mother's work schedule regularity	0.198
	Mother's work hour flexibility	0.182
	Mother having enough support for parenting the child	**<0.001**
	Mother having a current partner	**<0.001**
Maternal health and wellbeing	Mother's self-perceived health status	**<0.001**
	Mother's mental health (anxiety / depression / other)	0.698
Child demographics	Child's sex	0.735
	Child's ethnicity	**<0.001**

All associations were adjusted for seasonality. *see Appendix D

4.6.1.1 Home environment variables associated with indoor climate

For home environment factors, there was a greater likelihood of experiencing an indoor climate outside the optimal range (or a poorer indoor climate) at the weekday bedtime measurement for those children living in households experiencing crowding or those who used a non-bedroom area for regular sleeping (Figure 12).

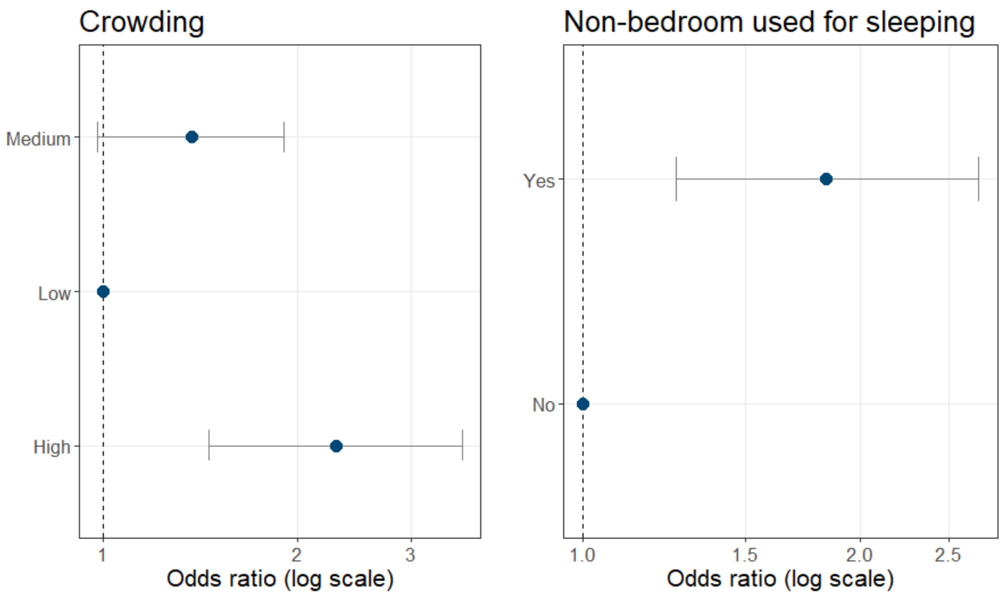


Figure 12. Adjusted odds ratios of having weekday indoor bedtime climate outside optimal range between 19°C and 28 Humidex according to home environment factors

4.6.1.2 Home environment-deprivation variables associated with indoor climate

For home-environmental-deprivation factors, there was a greater likelihood of experiencing indoor climate outside the optimal range (or a poorer indoor climate) at the weekday bedtime measurement for those children living in households experiencing a major problem with dampness or mould in their house or those who reported putting up with feeling cold or having a problem with house heating or keeping warm in winter (Figure 13).

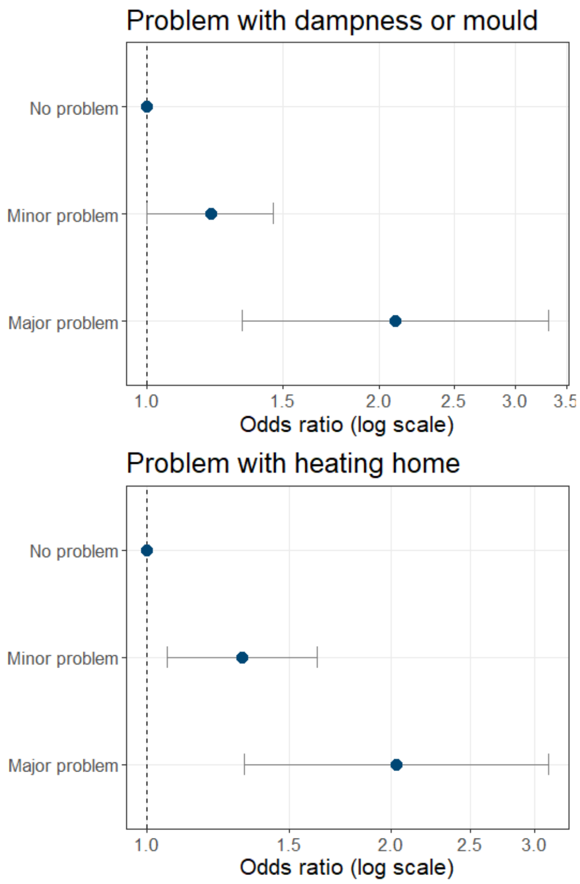


Figure 13. Adjusted odds ratios of having weekday indoor bedtime climate outside optimal range between 19°C and 28 Humidex according to home-environmental-deprivation factors

4.6.1.3 *Material deprivation variables associated with indoor climate*

For material deprivation factors, there was a greater likelihood of experiencing indoor climates which did not align to the optimal range (or a poorer indoor climate), specifically at the weekday bedtime measurement, for those children living in households that reported often running out of food, regularly not being able to afford to eat properly, and for those experiencing the lowest material wellbeing scores or the highest Dep-17 index score (Figure 14).

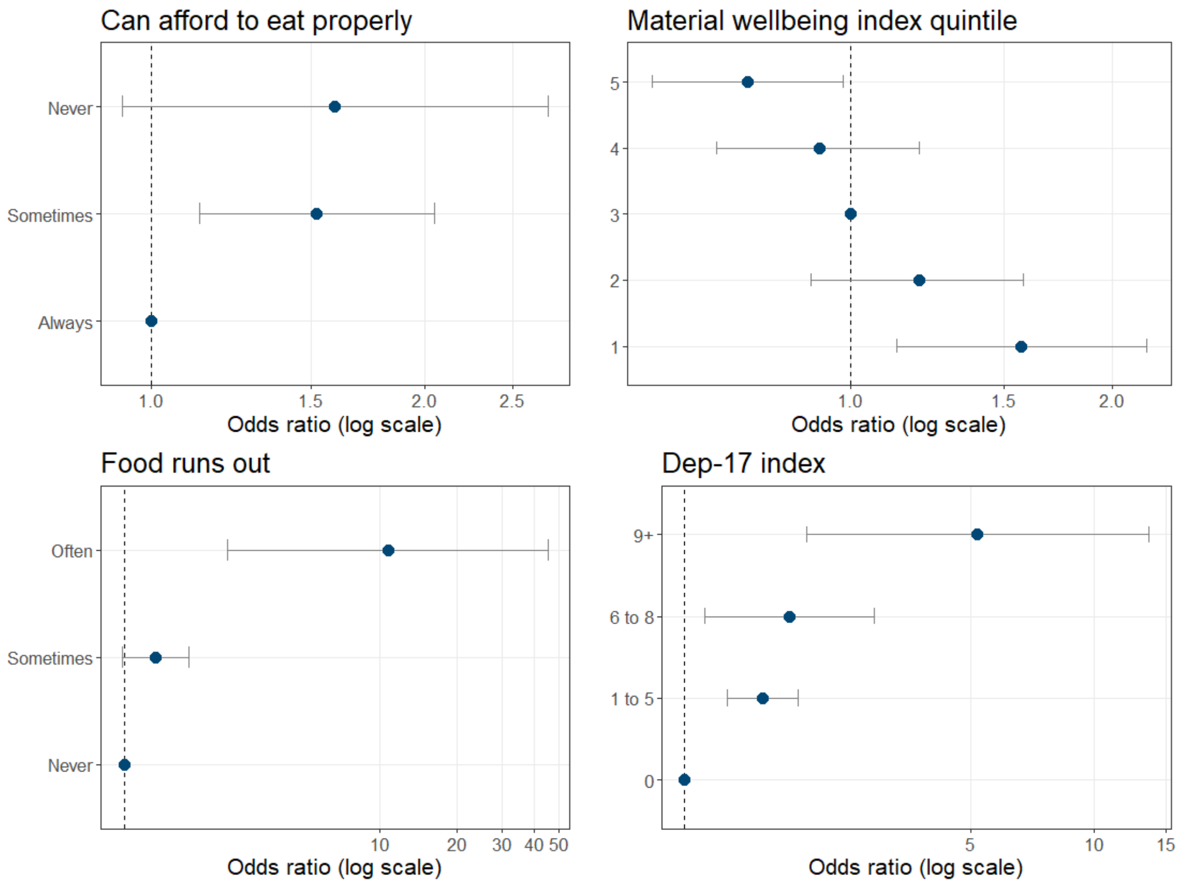


Figure 14. Adjusted odds ratios of having weekday indoor bedtime climate outside optimal range between 19°C and 28 Humidex according to material deprivation factors

4.6.1.4 *Housing and finance variables associated with indoor climate*

For housing and finance factors, there was a greater likelihood of experiencing indoor climate outside the optimal range (or a poorer indoor climate) at the weekday bedtime measurement for those children living in households that were not owned by their household, those paying rent rather than a mortgage and those on lower incomes (Figure 15).

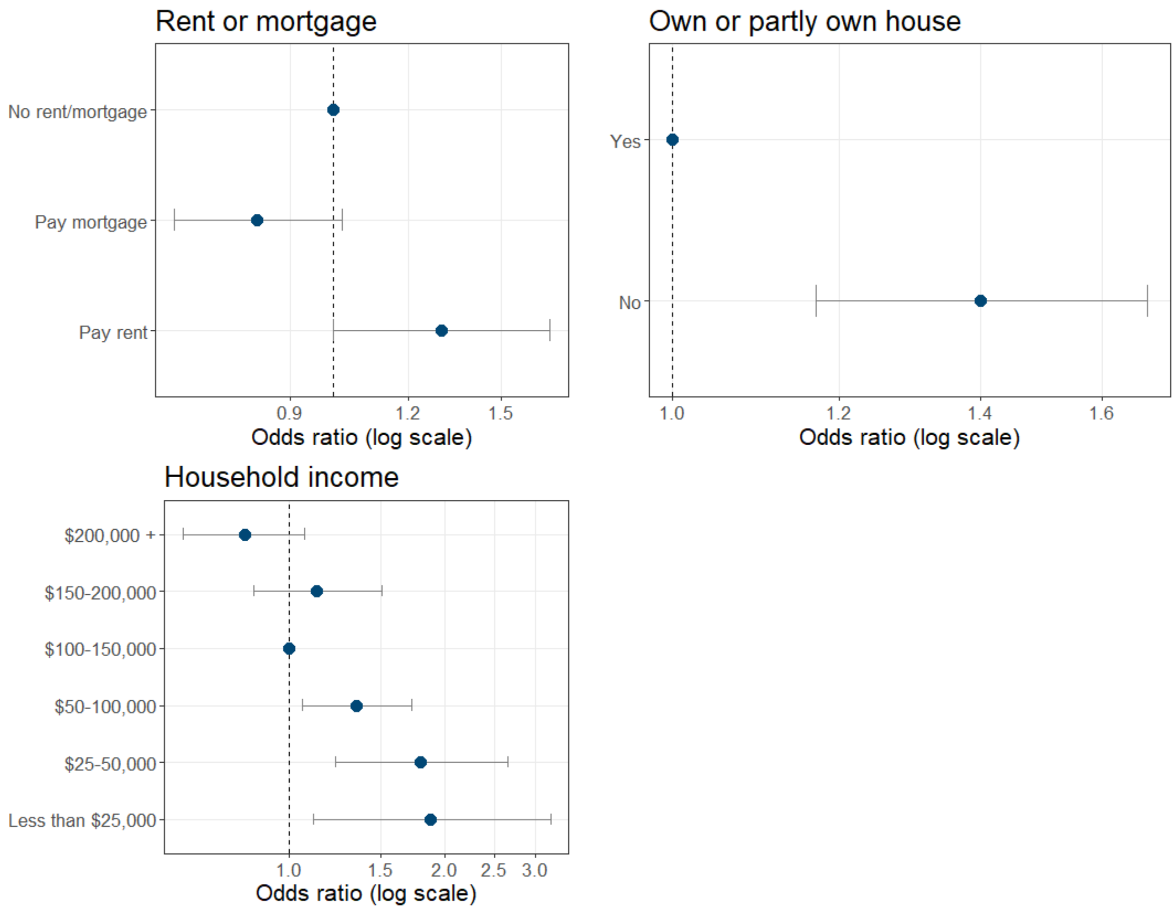


Figure 15. Adjusted odds ratios of having weekday indoor bedtime climate outside optimal range between 19°C and 28 Humidex according to housing and finance factors

4.6.1.5 Parenting variables associated with indoor climate

For parenting support factors, there was a greater likelihood of experiencing indoor climate outside the optimal range (or a poorer indoor climate) at the weekday bedtime measurement for those living in households where their mother did not have a current partner or reported not having enough parenting support (Figure 16).

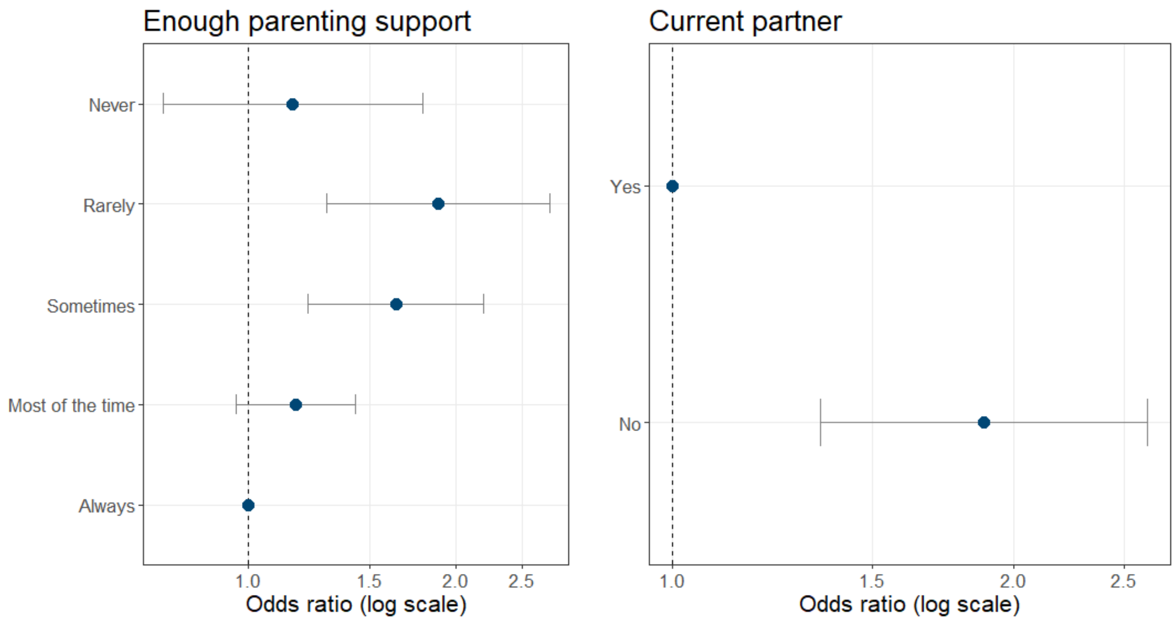


Figure 16. Adjusted odds ratios of having weekday indoor bedtime climate outside optimal range between 19°C and 28 Humidex according to parenting support factors

4.6.1.6 Maternal health variables associated with indoor climate

For maternal health factors, there was a greater likelihood of experiencing indoor climate outside the optimal range (or a poorer indoor climate) at the weekday bedtime measurement where the mother reported their general health as either good, fair or poor rather than very good or excellent (Figure 17).

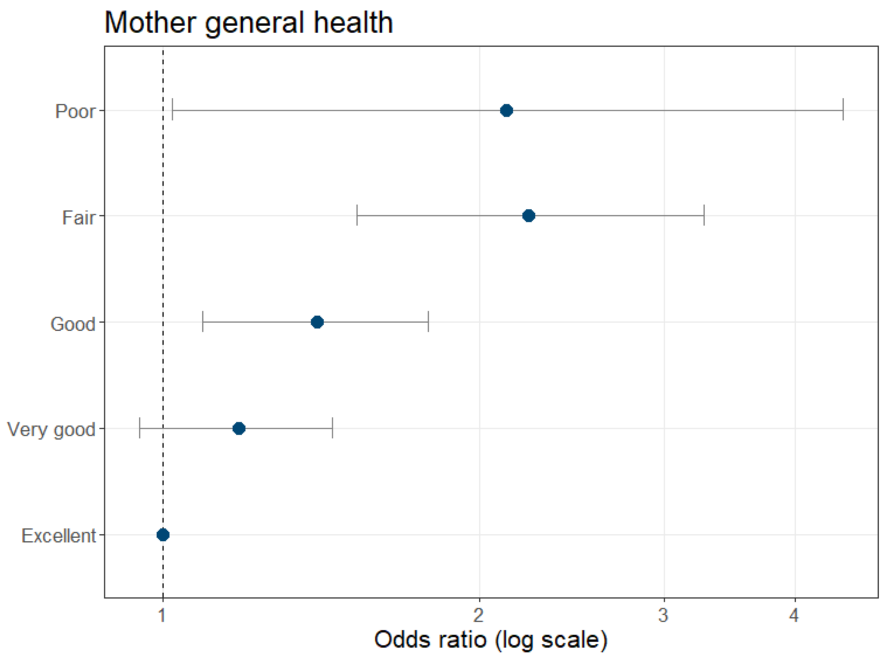


Figure 17. Adjusted odds ratios of having weekday indoor bedtime climate outside optimal range between 19°C and 28 Humidex according to maternal health factor

4.6.1.7 Demographic variables associated with indoor climate

For children's own reported ethnicity, there was a greater likelihood of experiencing indoor climate outside the optimal range (or a poorer indoor climate) at the weekday bedtime measurement for those children who identified themselves as Māori (odds ratio [95CI]: 1.63 [1.23-21.17], Pacific (1.86 [1.24-2.79]) or Asian (1.73 [1.26-2.36]) compared with New Zealand European children. When the logistic regression was repeated by the adding Dep-17 index and season as covariates for adjustment, the associations for those who identified as Māori (1.38 [1.02-1.88]) or Pacific (1.50 [0.93-2.43]) were attenuated, but those who identified as Asian remained approximately the same after adjustment (1.72 [1.18, 2.51]) (Figure 18).

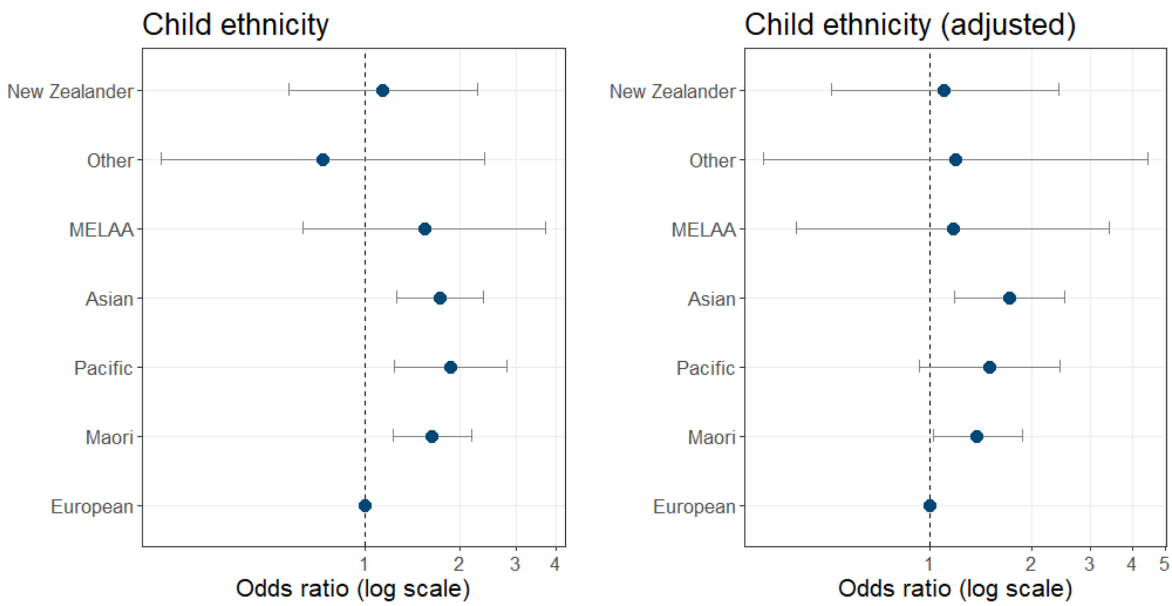


Figure 18. Adjusted odds ratios of having weekday indoor bedtime climate outside optimal range between 19°C and 28 Humidex according to ethnicity factor

5 Discussion

5.1 Summary of key findings

This bespoke research project sought to measure indoor climate variables at children's homes and schools as part of the routine *GUiNZ* eight-year DCW. Based on temperature, relative humidity, and Humidex, we used these measures to explore the optimal range of indoor climates that are associated with New Zealand children's concurrent health and wellbeing outcomes. We also explored what child and family sociodemographic factors are associated with exposure to the optimal climate range. Below we discuss the main findings of this report under four main headings: descriptive analyses; indoor climate, health outcomes and time-points; optimal range for temperature and Humidex; and sociodemographic factors associated with meeting the optimal indoor climate range.

5.1.1 Descriptive analyses

In measuring direct indoor temperatures being experienced by New Zealand children at eight years of age, we found that the average temperatures for both home and school were approximately 20°C. This is consistent with, and within the optimal range for, previously defined guidelines (e.g. WHO, 2006; WHO 2018). However, considerable variability for both home (10.3 to 29.5) and school (4.0 to 34.6) temperatures throughout the day indicated that many young children were experiencing a wide range of indoor temperatures in a 24 hour period.

5.1.2 Indoor climate, health outcomes and time-points

In evaluating the relationship between indoor climate measures and child health outcomes at eight years of age we found associations between indoor temperature and health outcomes, particularly for children's general health (reported by mother), as well as for their mental wellbeing, assessed via their depression and anxiety scores. We also found that suboptimal indoor temperatures (categorized in quintiles) tended to be associated with poorer reported general child health and increased anxiety and depression symptoms for children. This association was most pronounced for the indoor temperatures related to children's weekday bedtime.

Previous studies evaluating indoor climate (using similar measures such as temperature) and health outcomes in New Zealand have found similar results. An intervention study by Howden-Chapman and colleagues (2007) found that insulation interventions resulting in improvements in the indoor environment (e.g. change in mean bedroom climate from 13.6°C to 14.2°C and relative humidity from 68.6% to 64.8%) were associated with a reduced likelihood of reporting poor general health, low happiness and low vitality. Similarly, in a randomised controlled trial (RCT), Howden-Chapman and colleagues (2008) found that a more optimal indoor environment (higher indoor temperature) in the intervention group (living room: 17.1°C and child's bedroom: 14.8°C) was significantly associated with a lower likelihood of having poor general health (p <0.001), wheezing related to sleep disturbance (p <0.001) and dry cough at night (p=0.01), in comparison to the control group (living room: 16.0°C and child's bedroom: 14.3°C).

Another relevant study - the Pacific Islands Families: First Two Years of Life (PIF) Study also considered the impact of living in cold houses. This study was based on interviews with the mothers of a cohort of 1398 infants born in Auckland in 2000 (Butler *et al.* 2003; Paterson *et al.* 2006). While there were no direct measurements of indoor temperature and relative humidity of the participants' homes in this study, problems with cold housing were reported by 54% of mothers. Reported cold-housing was associated with a higher likelihood of having maternal asthma (OR [95CI]: 1.73 [1.10-2.71]) and probable maternal depression (1.57 [1.14-2.15]) based on Edinburgh Postnatal Depression Scale (Butler *et al.* 2003) as well as with the infant's odds of experiencing reported respiratory problems during the first six-weeks (1.41 [1.13-1.75]) (Paterson *et al.* 2006). In our more recent study, we did not find a similar pattern of association between indoor climate and asthma and/or respiratory illnesses in children who were in middle childhood (eight years of age). In middle childhood, using school measurements, we found only a marginally statistically significant association between the lowest temperature quintile at school in the morning and the odds of reporting higher depression scores using CESD-10 among the children (1.35 [0.96-1.92], p=0.089). The non-significant findings of these two health and wellbeing outcomes could be due to the improvement in housing quality in the time between the two studies, leading to warmer home indoor conditions in comparison to the housing conditions two decades ago and/or could be due to differences in the ages of the children in these studies. The former explanation is supported by winter indoor mean temperature data reported by Howden-Chapman *et al.* (2007).

While a number of measures recorded by the children were significantly associated with health outcomes, we determined that the most sensitive, in terms of predicting differences in wellbeing across the cohort, were from the readings taken at bedtime on a weekday. Further research is needed to examine why this reading was most sensitive but some evidence for the importance of overnight indoor climate variability and in-bed temperatures has been found by Saeki *et al.* (2015). There are likely to be additional confounding factors. For example, despite the covariate adjustments for the effects seasonality and individual household deprivation in the model results, unmeasured environmental and individual factors could still affect the indoor climate (Ormandy and

Ezratty 2012). Other confounding factors may also include air movement and ventilation variability, availability of heating, thermostatic control, solar irradiation, as well as activity level, body heat retention (e.g. clothing, blanket use) and stress status.

From the existing evidence, one study found body stress levels tend to be elevated on weekdays in comparison to the weekends (Schlotz *et al.* 2004). Such findings may provide a possible explanation for why the indoor measures on weekdays had a greater sensitivity to health and wellbeing outcomes overall. This is supported by our findings in Stage 2 and 3 (Figure 5 to Figure 8) that the associations with exposure-response patterns mainly involved the weekday measures rather than weekend measures.

Although direct comparisons cannot be made (given the differences in study methods and measurements), the pattern of findings show a similar trend in which suboptimal indoor temperatures (outside the optimal range) tend to be associated with a range of poor health outcomes for children.

5.1.3 Optimal range for temperature and humidex

Given the wide variability of temperature and humidity observed, we calculated cut-off points for determining the optimal range of temperature and Humidex levels using quintiles. Among the reviewed studies on the minimum indoor temperature, none has incorporated the measures of relative humidity. Hence, to our knowledge, the present study is the first to combine the temperature as the lower and Humidex as the higher cut-off points to describe a healthy indoor climate range.

For temperature, we found that children experiencing bedtime temperatures less than 19°C or greater than 25°C and Humidex values of less than 21 or greater than 28 were associated with increased odds of children experiencing poorer general health in middle childhood. For a combined temperature and Humidex model, we found that children experiencing bedtime temperatures less than 19°C or a Humidex value greater than 28 had increased odds of experiencing poorer general health.

Our indoor climate cut-off points (<19°C or >28 in Humidex) are consistent with previous recommendations, particularly for the optimal temperature cut-off. Notably, the WHO has proposed an optimal indoor home temperature range of between 18°C and 24°C for the general population in terms of maintaining good health (WHO 1987; WHO 1990). It has also been found that students (ages 14 -18) reported the most comfortable temperature range to be between 20°C and 27°C

(Tham *et al.* 2020). Additionally, previous studies have recommended a minimum temperature threshold of <18°C (Shiue *et al.* 2014) and a maximum temperature of >26°C for adults (Uejio *et al.* 2016). However, none of these studies in recent systematic reviews have defined an optimal indoor climate range using temperature for the lower and Humidex for the higher cut-off points (Jevons *et al.* 2016; Tham *et al.* 2020). Although valid and reliable evidence for the optimal temperature ranges for children remains sparse, it is reassuring that our temperature-Humidex cut-off points for children in this cohort study are consistent with the optimal temperature range reported by previous studies.

5.1.4 Family sociodemographics and achieving the optimal indoor climate range

In evaluating the relationship between indoor climate and sociodemographic factors we found that poorer indoor climates tended to be associated with poorer home environments characterised by: greater material deprivation/hardship; housing and financial difficulties; as well as low levels of perceived parenting support. We also found that suboptimal climate conditions (indicated by our indoor climate cut-off points of <19°C or >28 in Humidex) were associated with reported indoor environmental factors such as regularly experiencing problems with dampness and mould, and experiencing greater material deprivation (Material Wellbeing Index, Dep-17 Index), renting a home (rather than owning a home) and with greater household crowding.

Our findings are consistent with previous studies showing that poor indoor climate (cold homes) is associated with a household crowding, living in rented homes, and experiencing financial difficulties. For example, the PIF study (2000) found that the likelihood of living in cold homes was associated with household sizes of eight or more people, living in rental housing, and having greater difficulty meeting housing costs (particularly associated with lower household income) (Butler *et al.* 2003). A case-control study (2011- 2013) conducted with 642 two-year-olds in Wellington also reported a dose-response relationship between housing quality and acute respiratory infection hospitalisations (Ingham *et al.* 2019). The model covariates were evaluated using a directed acyclic graph (DAG) approach, which indicated that housing tenure, household crowdedness and socioeconomic status were theoretically and causally related to housing quality (Ingham *et al.* 2019). Lastly, an online survey of self-perceived thermal comfort among 656 adolescents found that 30% had “often” or “always” felt cold during winter at home (O’Sullivan *et al.* 2017). Sociodemographic factors associated with self-reported cold observations included living in rental housing and being of non-European ethnicity (Māori, Pacific People, Asian or Other) (O’Sullivan *et al.* 2017).

It is important to note that these studies did not measure the indoor climate directly, hence, their findings cannot be directly compared to the results of this bespoke study using the GUiNZ information. However, the pattern of findings in which indoor climate was outside the optimal range and associated with sociodemographic factors suggests that these home environmental and sociodemographic factors are important to address at a population level if indoor home environments are to be optimised to improve wellbeing for children and their families.

6 Implications

6.1 Legislations related to home indoor climate

At present in New Zealand, there are no regulations specifying the maximum indoor temperature (and relative humidity) in homes required or recommended to safeguard people from illnesses hypothesised to be caused by high air temperature and humidity. The findings of this report potentially have important implications for existing legislation in New Zealand concerning indoor climate and building regulations.

There are two pertinent regulations for this study: The Building Code within the regulations under the Buildings Act 2004 (New Zealand Legislation 2004) and the *Residential Tenancies (Healthy Homes Standards) Regulations 2019* administered by the Ministry of Housing and Urban Development (New Zealand Legislation 2019).

The Building Code is administered by the Ministry of Business, Innovation and Employment and states New Zealand Building Code (3^{rd} edition – Amendment 13) under Clause G5 (Interior Environment – Performance – G5.3.1), *habitable spaces, bathrooms and recreation rooms shall have provision for maintaining the internal temperature at no less than 16°C measured at 750 mm above floor level, while the space is adequately ventilated (Performance G5.3.1 shall apply only to old people's homes and early childhood centres)* (MBIE 2014). However, this regulation does not apply to children who experience premises other than early childhood centres. Health evidence supporting the mandated 16°C in internal temperature written into the Building Code can be traced back to a guidance document from the World Health Organization in 1990s (WHO 1990) citing a review study where the author suggests potential respiratory risks among older people when the indoor temperature is below 16°C (Collins 1986). Based on our Temperature-Humidex model, an indoor bedtime temperature of 16°C would be outside (below) the optimal indoor climate range for children and in this study was associated with a 75% (95CI: 32-133%) increased risk of suboptimal/poorer child health. Nevertheless, the Building Code under Clause G5 should achieve the objective to "*safeguard people from illness caused by low air temperature*". We suggest a higher minimum indoor temperature limit should be considered in practise.

The other important regulation pertinent to this study is the *Residential Tenancies (Healthy Homes Standards) Regulations 2019*. In this regulation, the heating standard (as in Clauses 8 to 10 and in Schedule 2) mandates landlords' to install fixed heating devices to protect tenants from cold stress to an extent that is capable of achieving a minimum temperature of at least 18°C in the main (or the largest) living room in winter.

This suggested minimum temperature of at least 18°C is close to our modelled cut-off point of 19°C for the child's bedroom at night. If we assume that the bedroom is not colder than the living room during bedtime and the indoor climate complies with the heating standard, then the current regulation of 18°C as a minimum temperature may be adequate. Nevertheless, this regulation protects children who live in rental premises only. It does not protect potentially vulnerable children who live in other home tenure types.

6.2 Climate change

On the 1st of September 2020, the ambient carbon dioxide (CO_2) level had reached 410 ppm as compared to 387 ppm on the same day in 2010 (NIWA 2020). With unchanged emission scenarios, the present CO_2 level will reach 560 ppm ("the doubling point of pre-industrial level") by the year 2060. Based on this "doubling point", a team of climate scientists from the World Climate Research Programme (WCRP) have just significantly narrowed the range of the elevated temperatures that are estimated to be between 2.6°C to 3.9°C (Sherwood *et al.*, 2020). This finding supports the previous Intergovernmental Panel on Climate Change (IPCC) assessment that there will be warmer and/or more frequent hot days and nights affecting public health (Woodward 2014).

Despite the repeated scientific efforts over the past 40 years that have predicted climate change effects on Earth (Voosen 2020), a recent review study has concluded that few studies have addressed impacts on the thermal environment indoors especially when assessing the health effects of heatwaves (Kownacki *et al.* 2019). In fact, in 2009, the WHO highlighted the lack of knowledge of severe heat on the indoor environment (WHO 2009; WHO 2018). Kownacki *et al.* (2019) have summarised in their review that the indoor temperature could increase by up to 50% more in indoor temperatures compared to outdoor.

If climate change predictions are accurate, and the few epidemiological findings as mentioned above are correct, similar health impacts in the indoor environment may occur in New Zealand. At present, there is very little research available that has investigated the potential health impacts in New Zealand due to extended summer duration (Harrington 2020) alongside the impacts of climate change induced warmer winters (Ministry for the Environment 2020). In light of potential climate change impacts on heat-related health problems in children, the present study provides policy-makers with some evidence for optimal cut-off points that may be used to assess the likely expected impact of climate change on health and wellbeing.

7 Limitations

7.1 Measurement bias in indoor climate data

The current project measured temperature and humidity using a small, inexpensive, digital gauge in comparison to the larger, more expensive, and sophisticated climate data-logger that was trialled during our pilot study in 2017 (Lai *et al.* 2017). The reasons for choosing the digital gauge were:

- It was smaller in size so that young children could carry it with them safely, allowing measurements over a wider range of time points across each day, and in spaces that children spend their time such as the classroom.
- They required no specialised training in comparison to the more sophisticated data-logger that required start/stop data-log procedures and regular re-calibration for monitor sensors.
- They required no battery maintenance over a long period, allowing more than a year of time for the completion of the main cohort without the need to recharge or replace the batteries.
- They were easy to use for children of eight years of age with simple instructions given by the interviewers, enhancing participant engagement (children were asked to be 'scientists' when collecting the temperature and humidity data).
- They were affordable and therefore there was less impact if they were lost (as was the case for half of the monitors at least) or damaged.

Despite the advantages, our selected approach based on child's measurement using a handheld digital gauge may have been prone to measurement bias. For example, children may have taken recordings in extreme sunlight so the recorded measure may not have reflected the ambient room temperature. However, this type of bias may have been reduced by having a greater number of observations (as in our present study) and by using statistical methods to handle extreme values and outliers (Appendix C).

7.2 Measurement bias in Time Use Diary data

We have identified various types of errors in the children's written records of the date, time, temperature, and relative humidity. The findings in the present study assume that poor quality in handwritten records (including missing data) from the children at eight years of age happened at random. However, it is possible that children's understanding of the interviewers' instructions as well as their numeracy and literacy development could have been affected by their family's socioeconomic status (Cavadel and Frye 2017). We have reduced this potential bias by using pattern recognition in order to systematically recover 1-4% of written errors in the indoor climate records. These procedures have also resolved the written errors and format variations in the date/time records so that 96-99.9% of data could be used in our analyses (Appendix B).

In addition, the Time Use Diary response rates were also likely biased. We have however examined the response rates across various sociodemographic factors (Table 3). A large proportion of the TUDs not being returned (52%) differed from the smaller pilot study (TUD questions were less open-ended, and only 9% were not returned) (Lai *et al.* 2017) and could be partly related to the updated design of the self-administered TUD data collection in the main cohort study. Investigations of this topic are outside the scope of the present study. However, the proportion of responses we received still provided sufficient statistical power to explore associations and to identify the most sensitive indoor measures that related to patterns of current child health.

As mentioned in Section 4.1, children in low deprivation and less vulnerable groups had higher return rates for the TUDs. Due to the bias in the demographic characteristics of children in the cohort who returned TUDs, it is possible that the findings of this study may underestimate the true impact of indoor climate measures on child wellbeing across the full cohort and for all New Zealand children.

7.3 Proxy measure of the child's general health

Mother-reported child general health at the time of the interview was the most sensitive outcome from the 20 different health and wellbeing outcomes investigated (3.1.4). However, there may be potential bias due to discordance between parents and children in participant-reported health (Davis *et al.* 2007). The possible discordances could be due to differences in understanding and interpretation of the question (Jokovic *et al.* 2004). It is possible that children would provide more extreme scores (high or low) as they tend to base their responses on single reasons rather than considering multiple reasons or examples (Davis *et al.* 2007). Overall self-reported measures have however been shown to be a good proxy for general health in a multitude of international wellbeing studies at all ages. Further at the eight-year interview while children tended to report lower general wellbeing than their parents reported on their behalf there was concordance between the relative rankings of wellbeing overall (Morton *et al.* 2020).

8 Conclusion

The current study accessed information collected from the *Growing Up in New Zealand* cohort at eight years of age, including direct indoor environmental measures added specifically for this research with BRANZ. The results of analyses of the data received showed that children in the cohort experience a wide range of indoor climates, even after accounting for seasonality. This variability is hidden in the average temperatures for both home and school environments, which were approximately 20°C in each case (3-6°C warmer than the reported indoor conditions in 2001, Howden-Chapman *et al.* 2007). The variability was only apparent as a result of several measures being recorded across the day and exploration of all these measurements.

Considering all the measures made by the children, the most sensitive in terms of association with their concurrent wellbeing was that made just before they went to bed on a weekday. In particular a clear U-shaped dose-response relationship was observed between the child's general health (reported by their mother) and the child's weekday bedtime measurement, with poorer wellbeing being associated with more extreme measures. These were the most sensitive measures from the range of measures explored for indoor climate and health and wellbeing outcomes and were identified following a systematic screening process and multiple in-depth analyses. This finding is consistent with the reported patterns of health effects both in New Zealand and overseas.

The current study also presents initial evidence for an ideal minimum (19°C) and maximum (Humidex= 28) indoor climate range for optimising child health and wellbeing in young children growing up in New Zealand today. This temperature range may be particularly useful when reviewing the existing legislation on home indoor climate in New Zealand especially in relation to the *Building Code* and the *Residential Tenancies (Healthy Homes Standards) Regulations 2019*.

Also, importantly this study has demonstrated that young children are more likely to be exposed to poorer indoor climate conditions (< 19°C or > Humidex 28) if their families are living in poverty (using a variety of sociodemographic measures). Addressing child poverty may also assist with the likelihood that families may be better enabled to optimise the indoor environments that their young children are exposed to for a significant proportion of their daily lives. Future research could also explore whether physical dwelling features (e.g. building size, type, condition, and age – differences between older and newer houses) may influence indoor climate and occupant's health and wellbeing.

In summary, we have presented direct evidence of the indoor climate being experienced by contemporary New Zealand children at eight years of age in their homes and at school and demonstrated that exposure to differential temperature and humidity measures are associated with their health and wellbeing in ways that are consistent with the ecological evidence and that support the premise that healthy homes are important for optimising wellbeing for all New Zealand children. However, we have also demonstrated that the socio-demographic profiles of the children's families may limit the potential for families and children to experience these optimum environments, and this inequity in opportunities to support wellbeing needs ongoing and urgent attention.

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Appendices

A. Data linkage with NIWA station records

In order to reduce spatiotemporal errors with respect to local climate variability, we used weather stations to represent the local climate at the children's homes. First, we used cluster analysis (average linkage method) to aggregate all children's home locations at eight-year data collection wave into 100 clusters.

At the centroid point of each cluster, we matched to the nearest NIWA station that contained the hourly time series of temperature (°C) and relative humidity (%) data. These hourly data were obtained from the NIWA online database (https://cliflo.niwa.co.nz/).

During the matching process, some neighbouring clusters that shared the same weather station were merged and we calculated a new centroid point. The final list below contains 63 NIWA stations.

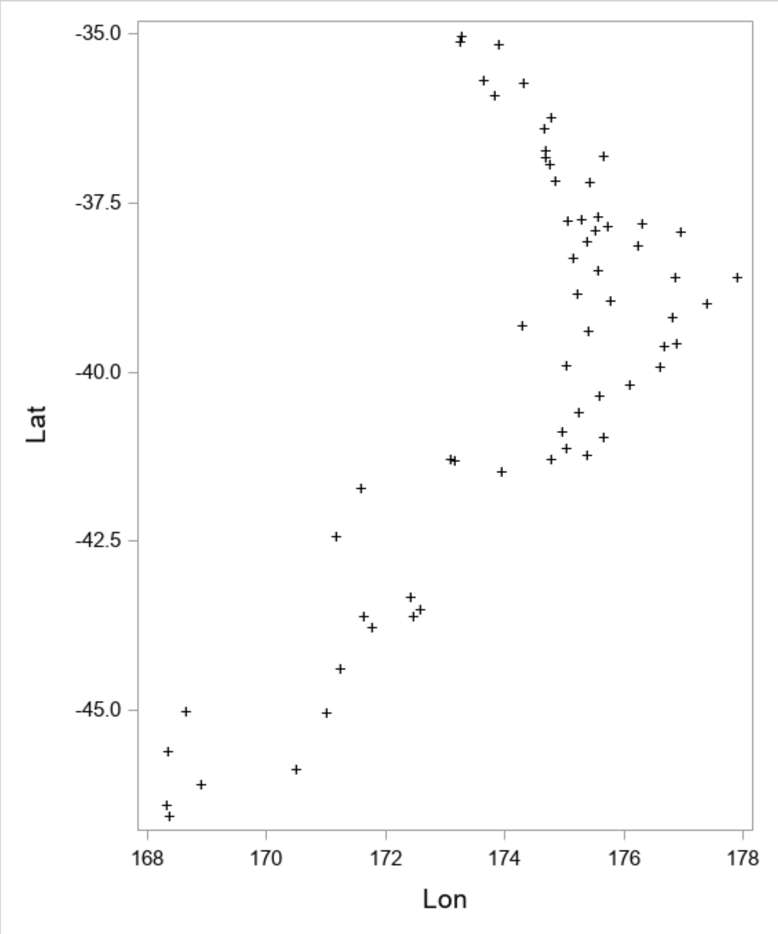
The mean distance of the NIWA stations from the cluster centroid points was 12.3 km (SD=10.6).

Table A 1. List of 63 NIWA weather stations.

Cluster no.	Cluster centroid Latitude	Cluster centroid Longitude	Selected NIWA Station number	NIWA Station Latitude	NIWA Station Longitude	NIWA station location	Distance between station and cluster centroid point (km)
1	-	168.3258	12444	-46.4173	168.3305	Invercargill Aero 2 Ews	1.4
2	-	171.8009	42899	-43.7894	171.7903	Winchmore 2 Ews	8.4
3	-	172.6242	24120	-43.5307	172.6077	Christchurch, Kyle St Ews	3.2
4	-41.229	174.8361	41212	-41.3024	174.8057	Wellington, Greta Point Cws	8.6
5	-	175.5973	21963	-40.382	175.6092	Palmerston North Ews	7.1
6	-	175.0674	3715	-39.937	175.0451	Wanganui,Spriggens Park Ews	2.5
7	-	176.8802	15876	-39.607	176.9115	Whakatu Ews	3.0
8	-	176.0122	25643	-38.9735	175.7908	Turangi 2 Ews	31.8
9	-	176.7534	26719	-38.6184	176.8739	Tarapounamu Ews	14.1
10	-	175.7861	37016	-38.517	175.58	Pureora Forest Cws	18.9
11	-	175.7839	17030	-37.877	175.735	Matamata, Hinuera Ews	4.7
12	-	175.3099	41389	-38.0947	175.3876	Waikeria Ews	9.9
14	-	176.8951	40982	-37.9482	176.9677	Whakatane Ews	8.0
15	-	175.467	37656	-37.925	175.54	Lake Karapiro Cws	8.9
17	-	175.2756	26117	-37.7739	175.3052	Hamilton, Ruakura 2 Ews	2.6
18	-	176.2038	12428	-37.822	176.324	Te Puke Ews	16.3
19	-	175.1294	25162	-37.7883	175.0691	Whatawhata 2 Ews	16.6
20	-	175.6256	23908	-37.7196	175.5853	Toenepi Ews	15.8
21	-	175.5372	38619	-37.2151	175.4505	Firth of Thames Ews	11.4
22	-	174.9052	22719	-36.9618	174.7764	Auckland, Mangere Ews	11.9
23	-37.22	174.8233	2006	-37.2064	174.8638	Pukekohe Ews	3.9
26	-	174.7499	41351	-36.863	174.7119	Auckland, Motat Ews	4.4
27	-	175.7229	40981	-36.828	175.672	Whitianga Ews	7.6
28	-36.539	174.7078	17838	-36.4344	174.6677	Warkworth Ews	12.2
29	-	174.5275	1340	-36.2711	174.799	Leigh 2 Ews	29.7
30	-	174.3367	40980	-35.744	174.329	Whangarei Ews	1.2

31	-	176.0672	41077	-38.146	176.258	Rotorua Ews	17.4
33	-	173.4476	37131	-35.7204	173.6515	Trounson Cws	26.4
36	-	174.4701	37852	-36.7483	174.7138	Auckland, North Shore Albany	21.9
38	-	175.1388	23899	-38.3317	175.1536	Te Kuiti Ews	1.3
40	-	170.4929	15752	-45.9013	170.5147	Dunedin, Musselburgh Ews	3.2
42	-38.917	175.2962	40983	-38.8615	175.2381	Taumarunui Ews	8.0
43	-	172.4036	17603	-43.6262	172.4704	Lincoln, Broadfield Ews	7.0
46	-	173.0676	21937	-41.3173	173.0948	Appleby 2 Ews	5.9
47	-	171.2001	23934	-42.4602	171.1916	Greymouth Aero Ews	0.7
48	-	174.1454	23872	-39.3355	174.305	Stratford Ews	23.1
50	-	173.232	40751	-41.3277	173.1862	Richmond Ews	4.4
51	-	173.9154	1056	-35.183	173.926	Kerikeri Ews	9.1
53	-	173.9402	12430	-41.4989	173.9629	Blenheim Research Ews	3.0
55	-	175.0705	40750	-41.1403	175.0428	Upper Hutt, Trentham Ews	3.2
57	-	175.5851	40984	-40.9816	175.6793	Masterton Ews	8.1
58	-	173.4136	18183	-35.0677	173.2874	Kaitaia Aero Ews	11.8
59	-	168.8192	41331	-45.0348	168.6636	Queenstown Ews	14.6
62	-	175.0939	12442	-40.9039	174.9844	Paraparaumu Ews	12.4
66	-	178.0328	24976	-38.6275	177.9218	Gisborne Ews	10.5
67	-	175.2582	41352	-40.627	175.2619	Levin Ews	9.2
70	-	176.5795	31620	-39.9515	176.6171	Waipawa Ews	6.1
71	-	173.2457	17067	-35.1335	173.2629	Kaitaia Ews	1.7
77	-	176.6289	40256	-39.638	176.6821	Maraekakaho Cws	5.9
78	-	171.2533	35703	-44.4105	171.2543	Timaru Ews	11.6
79	-	170.944	40986	-45.057	171.023	Oamaru Ews	7.2
81	-	168.6967	42975	-46.1238	168.9194	Gore Ews	23.6
84	-	175.8152	26958	-40.2081	176.1103	Dannevirke Ews	31
85	-	174.1946	25119	-35.9315	173.8532	Dargaville 2 Ews	44.3
86	-	168.5094	40845	-45.6259	168.367	Five Rivers Cws	11.1
88	-	175.4612	21938	-41.2523	175.3899	Martinborough Ews	7.0
89	-	172.2261	39224	-43.3573	172.4322	West Eyreton, Arundel Farm	22.3
90	-	176.6446	39944	-39.2243	176.8388	Totara Cws	18.4
94	-	168.1253	5823	-46.587	168.376	Tiwai Point Ews	39.8
96	-	171.533	36645	-43.6398	171.6521	Methven Cws	31.5
98	-	171.5719	41382	-41.743	171.612	Westport Ews	3.5
99	-	175.7957	31621	-39.418	175.413	Ohakune Ews	43.9
100	-	177.4102	3126	-39.017	177.413	Wairoa, North Clyde Ews	5.6

Figure A 1. Locations of 63 NIWA weather stations used in this project



'+' marker: NIWA weather station

Table A 2. NIWA Outdoor hourly climate data matched by geographical clusters, dates and rounded hours of the indoor measurement records (after outlier removal stage, see *Appendix C**).*

TEMPERATURE (°C)									
TUD periods		N	Mean	S.D.	Min	Percentile			Max
						25th	50th	75th	
Week day	Woke up	2079	11.3	4.6	-2.8	8.2	11.4	14.2	24.1
	Got to school	1774	12.6	4.6	-1.9	9.8	12.4	15.6	23.8
	Lunch at school	1897	16.7	4.0	6.2	13.8	16	19.1	30.9
	Got home	1660	16.5	3.9	7.2	13.9	15.8	18.9	32.2
	Went to bed	1747	13.2	4.0	0.1	10.4	12.8	15.8	25.5
Week end	Woke up	1953	11.6	4.8	-3.5	8.3	11.9	14.7	25.8
	Dinner	1710	15.1	3.9	4.8	12.4	14.3	17.4	29
	Went to bed	1690	13.5	3.8	2.7	11	13.1	16.1	25.6
RELATIVE HUMIDITY (%)									
TUD periods		N	Mean	S.D.	Min	Percentile			Max
						25th	50th	75th	
Week day	Woke up	2017	89.1	9.4	26	84	92	97	100
	Got to school	1714	84.7	11.5	40	76	86	95	100
	Lunch at school	1846	69.0	12.1	20	61	68	77	100
	Got home	1613	67.8	12.1	23	59	67	76	100
	Went to bed	1703	82.6	9.5	27	76	83	91	100
Week end	Woke up	1895	88.5	10.0	24	83	91	97	100
	Dinner	1662	75.8	12.1	34	68	76	85	100
	Went to bed	1640	82.6	10.1	33	76	84	90	100

B. Data cleaning

Data collected for the indoor climate analysis comprised of multiple time points in four different fields: date, time, temperature, and humidity. The nature of the data collection, being handwritten by a child in a free-text format in the Time Use Diary, meant that significant cleaning and standardisation was required before it was in a usable format for analysis. The types of methods required to prepare the datasets were specific to the data type and for each field, a combination of automated and manual cleaning methods was used. In all cases where the issues could not be addressed, we checked the original records in the source data (scanned copy of the Time Use Diary) for that participant to see if the issue was made at the data entry point.

Table A 3. Total number of responses for each variable type and the percentages of records that were entered in correct format, required systematic data cleaning, and the final percentages used in subsequent data analyses.

Data type	Total Responses	Entered in correct format	Required systematic data cleaning	*Final % for data analyses
Date	3801	2.7%	97.2%	99.9%
Time	21304	28.0%	68.4%	96.4%
Indoor temperature	16615	95.3%	3.9%	99.1%
Indoor relative humidity	16455	98.1%	1.0%	99.0%

*the remaining percentages (0.01% to 3.6%) that were unable to be cleaned represented as missing in the final dataset

Data cleaning for date, time, indoor temperature and indoor relative humidity variables were processed systematically using R programming scripts (www.r-project.org). Our methods are described below:

1. Date

Children were required to specify both the week and weekend day in which they would take readings of indoor temperature and relative humidity at various time points. Data cleaning done in this field was to address date format standardisation issues, typographical errors and inference of missing date information. We used R scripts to address common typographical errors such as single letter transpositions, and then convert all complete date responses to dd/mm/yyyy format.

Where an incomplete date was given by the participant, the missing information was assumed to be the first corresponding date following the interview where the Time Use Diary was assigned to the participant. See examples in Table A4.

Table A 4. Examples of Time Use Diary recording date inference from interview date.

Time Use Diary date (with incomplete information)	Interview date	Inferred date to be used for data analysis
"Thursday 31st"	30/08/2017	31/08/2017
"Sunday"	13/07/2017	15/07/2018
(No information entered)	23/01/2019	24/01/2019

2. Time

At each time point the child recorded climate data, they were first required to record the time that the reading was taken. An R script was used to address formatting issues and am/pm errors which were inferred based on the answer category. Manual cleaning methods were used for the remaining record errors which eluded the filters in the R script. The issues addressed in cleaning could be grouped into the following categories:

Table A 5. Summary of time error types addressed in data cleaning process.

Error type	Description
Format	Time value entered had an incorrect format – e.g. had text included ("10 in the morning"), lack of or incorrect punctuation ("1000", "10,00")
AM/PM	Appears as if AM and PM were confused by participant or data enterer
Nonsensical	Answer given had impossible time (e.g. "84:40")
Range	Time range was given (most appropriate was chosen based on field)
Typo	Obvious data entry error (e.g. "41:0")

Unspecified	Data field had information entered but no possible indication of time

3. Temperature

All participants were assigned the same type of monitor for temperature readings. These monitors display a temperature reading to one decimal place and can be switched between Celsius and Fahrenheit with one click of a button. Below are some common issues that were addressed in the cleaning process:

Table A 6. Summary of temperature error types addressed in data cleaning process.

Error type	Description
Decimal	Decimal place was missing, or in the wrong place
Combined	Relative humidity value was amended to the end of the temperature value
Fahrenheit	Answer given was clearly Fahrenheit recording
Character	Answer had a non-numeric character in it or symbol other than decimal place
Number	Answer given had impossible number of digits

4. Humidity

Humidity values required significantly less cleaning than temperature and time values. The two common error types addressed in the data cleaning are displayed in the table below:

Table A 7. Summary of humidity error types addressed in data cleaning process.

Error type	Description
Decimal	Value was given to one decimal place but monitor only gives whole numbers
Character	Answer had a non-numeric character

C. Outlier detection

Methodology

In the TUD, the GUiNZ cohort children have monitored the indoor climate and recorded their measurements on one weekday when they woke up, got to school, had school lunch, got back home, and went to bed, and on one weekend day – including when they woke up, had dinner, and went to bed. Indoor measurement recording was at bedtime, but not necessarily when they went to sleep.

Our outlier detection methodology aims to reduce potential influential points that could become biases in the main data analyses while avoiding inflation of Type I error due to over-exclusion (Bakker & Wicherts 2014). Potential outliers in both the indoor climatic values and their measurement time were detected using the following methods for exclusion and inclusion:

1. Univariate method for exclusion:

- Time records are the basis of the TUD data. The sequence of the daily TUD periods provides us with the first deductive method to handle abnormal (usually extreme) time records *a priori*.
- Before detection of any non-sequential time records, we transformed over-midnight records, which were found in weekday and weekend bedtime. We applied two limits for such transformation (bedtime values ≤9 am) to ensure a wider coverage of possible real records before we determined if they were outliers. These time records, e.g. 1 am and 2 am, were transformed to 25 (for 1 am) and 26 (for 2 am) so that the statistical reasoning and sequential logic of these values preserved when comparing with other time records before midnight.
- Non-sequential time records on the same day were detected systematically using the following logics:
    - if '*Weekday - Wake up*' and '*Weekday - School*' are non-missing and '*Weekday - School*' < '*Weekday - Wake up*'
    - if *'Weekday – Lunch'* is non-missing and *'Weekday – Lunch'* < the maximum record among '*Weekday - Wake up*' and '*Weekday - School*'
    - if *'Weekday – Home'* is non-missing and '*Weekday – Home*' < the maximum record among '*Weekday - Wake up*', '*Weekday - School*' and *'Weekday – Lunch'*

- if *'Weekday – Bed'* is non-missing and *'Weekday – Bed'* < the maximum record among '*Weekday - Wake up'*, '*Weekday - School'*, *'Weekday – Lunch'* and *'Weekday – Home'*

(if any of the above conditions were met, then weekday non-sequential time record was detected)

- if *'Weekend - Wake up'* and *'Weekend – Dinner'* are non-missing and *'Weekend – Dinner'* < '*Weekend - Wake up'*
- if *'Weekend – Bed'* is non-missing and *'Weekend – Bed'* < the maximum record among '*Weekend - Wake up'* and '*Weekend – Dinner*'

(if any of the above conditions were met, then weekend non-sequential time record was detected)

- These records were found among the TUD of 46 children, e.g. got to school at 8am but the school lunchtime was recorded oddly as 10pm and then got home normally at 3pm. All non-sequential records were above or below the 95th or 5th percentile and were replaced by the median time values of the periods.
- Remaining time records that were still far deviated from the TUD periods for monitor reading, e.g. 5am as the lunchtime at school, 12.30pm as dinner time, were detected systematically using 4-sigma rule (mean ± 4 SD). Time records beyond 4-sigma were regarded as outliers and were excluded from the main analyses that will be presented in the final report.
- For each TUD period, on average, ten outliers of time recordings were excluded.

2. Multivariate method for exclusion:

- Indoor climatic records were assessed by Lund's test (Lund 1975; Rotondi & Koval 2009) that examines the studentized residuals from a multivariate model. Lund (1975) had derived a formula for sample size up to 100, and Rotondi and Koval (2009) had expanded this formula for sample size up to 1000. Despite the Lund's test value limit tends to stabilize at around 4 when sample size reaches 1000, there are no further studies on expansion of the sample size beyond 1000 at the time of our reporting.
- We therefore empirically fitted the sample size values against the derived Lund's test value limit from Rontondi and Koval (2009). We assessed various curve-linear models and have based on R^2 to choose the optimal one, a logarithmic model (R^2=0.998): *Value limit = 2.134 + 0.278*ln(sample size)*, to statistically project the Lund's test value limits up to a sample size of 2000 to suit the range of our study sample size in this project. Based on the logarithmic

model, we used a projected Lund's test value limit of ±4.2 (at alpha=0.05) to assess studentized residual values for a model with five covariates. Studentized residuals that exceeded this projected Lund's test value limit were regarded as potential outliers according to Lund (1975).

- We used Generalized Estimating Equations (GEE) to obtain residuals of the predicted indoor climate records adjusted for linked NIWA outdoor data, household deprivation level (54-month), year, month of the year, and hour of the day. The GEE model also accounts for the random effects for individual-level residual covariance structure.
- Potential outliers of indoor climate records in each TUD period have been detected. E.g. indoor wake-up temperature being too high (36.5°C to 55°C) when the outdoor temperature was 10.3°C to 14.5°C, indoor bedtime temperature being too low (2°C to 2.9°C) when outdoor was 10.4°C to 17.3°C, indoor school RH being too low (4% to 19%) when the outdoor RH was 63% to 94%. For each TUD period, on average, eight indoor climate outliers were excluded.

Results

Potential outliers of time records were detected by 4-sigma rule, which screens values above or below 4 times the standard deviations from the mean.

Table A 8. Time (Hour) records.

BEFORE REMOVAL OF OUTLIERS BY 4-SIGMA RULE						Percentile			
TUD periods		N	Mean	S.D.	Min	1st	50th	99th	Max
Week day	Woke up	2107	7.0	0.7	1.3	5.5	7.0	9.1	11.7
	Got to school	1803	8.5	0.4	4.6	7.2	8.5	9.8	14.1
	Lunch at school	1920	12.6	0.7	5.2	10.5	12.5	14.2	17.0
	Got home	1688	15.8	1.1	12.5	14.4	15.4	20.0	21.6
	Went to bed	1763	20.4	0.8	16.0	18.8	20.3	23.0	24.2
Week end	Woke up	1971	7.3	1.0	1.0	5.2	7.2	10.0	13.0
	Dinner	1730	18.4	0.9	12.7	15.6	18.4	21.0	23.8
	Went to bed	1709	20.6	1.0	17.8	18.8	20.5	24.0	28.0
AFTER REMOVAL OF OUTLIERS BY 4-SIGMA RULE						Percentile			
TUD periods		N	Mean	S.D.	Min	1st	50th	99th	Max
Week day	Woke up	2095	7.0	0.7	4.2	5.5	7.0	9.0	9.8
	Got to school	1786	8.5	0.3	7.0	7.4	8.5	9.5	10.3
	Lunch at school	1913	12.6	0.6	10.0	10.5	12.5	14.2	15.2
	Got home	1673	15.8	1.0	12.5	14.4	15.4	19.0	20.0
	Went to bed	1760	20.4	0.8	17.8	18.8	20.3	22.8	23.5
Week end	Woke up	1964	7.3	0.9	3.8	5.3	7.2	10.0	11.0
	Dinner	1720	18.4	0.9	14.9	16.3	18.4	21.0	22.0
	Went to bed	1700	20.6	1.0	17.8	18.8	20.5	23.6	24.2

Potential outliers of indoor climatic records were detected by projected Lund's test value limits so that multivariate studentized residual values above or below the limits were regarded as outliers.

Table A 9. Indoor temperature records.

TEMPERATURE (°C) BEFORE REMOVAL OF OUTLIERS						Percentile			
TUD periods		N	Mean	S.D.	Min	1st	50th	99th	Max
Week day	Woke up	2036	18.6	3.57	2.5	11	18.4	27.5	55
	Got to school	1700	18.96	3.69	1	10	18.9	28.5	42.2
	Lunch at school	1748	21.4	3.77	3	12.2	21.1	31	46
	Got home	1548	21.62	3.81	2	13.9	21.2	31.4	43.8
	Went to bed	1615	21.09	3.45	2	11	21.1	29.1	41.1
Week end	Woke up	1887	18.49	3.46	4	10	18.4	27.5	36.5
	Dinner	1573	21.39	3.43	1	12	21.3	29	44.4
	Went to bed	1570	21.07	3.32	2	11.5	21.1	28.7	34.1

AFTER REMOVAL OF OUTLIERS BY LUND'S TEST						Percentile			
TUD periods		N	Mean	S.D.	Min	1st	50th	99th	Max
Week day	Woke up	2027	18.55	3.32	3.6	11	18.4	26.4	33
	Got to school	1689	18.91	3.48	4	10.5	18.8	27.4	32.1
	Lunch at school	1739	21.38	3.57	10.1	12.3	21.1	30.1	37.2
	Got home	1538	21.6	3.55	11.1	14.4	21.2	30.4	37.8
	Went to bed	1607	21.11	3.24	9.4	12.2	21.1	29	34.1
Week end	Woke up	1881	18.49	3.36	5	10.1	18.4	27.1	33.1
	Dinner	1563	21.43	3.13	8.8	13.4	21.3	28.8	33.9
	Went to bed	1562	21.11	3.15	9	12	21.1	28.6	32.8

Table A 10. Indoor relative humidity records.

RELATIVE HUMIDITY (%) BEFORE REMOVAL OF OUTLIERS									
TUD periods		N	Mean	S.D.	Min	Percentile			Max
						1st	50th	99th	
Week day	Woke up	2094	64.82	10.9	4	27	65	90	99
	Got to school	1747	62.69	11.1	4	22	63	89	99
	Lunch at school	1785	61.28	11.2	6	30	61	91	99
	Got home	1636	60.13	10.4	20	36	60	88	99
	Went to bed	1669	61.29	10.6	4	30	61	87	99
Week end	Woke up	1922	64.34	11.6	2	23	64.5	91	99
	Dinner	1648	61.41	11.2	4	31	61	90	99
	Went to bed	1621	61.64	11.1	4	30	61	90	99
AFTER REMOVAL OF OUTLIERS BY LUND'S TEST									
TUD periods		N	Mean	S.D.	Min	Percentile			Max
						1st	50th	99th	
Week day	Woke up	2081	65.14	10.1	16	40	65	90	99
	Got to school	1736	63.02	10.3	11	32	63	89	99
	Lunch at school	1780	61.41	10.9	11	35	61	91	99
	Got home	1636	60.13	10.4	20	36	60	88	99
	Went to bed	1663	61.48	10.2	16	36	61	87	99
Week end	Woke up	1906	64.79	10.6	15	36	65	91	99
	Dinner	1643	61.56	10.9	6	35	61	90	99
	Went to bed	1612	61.9	10.5	20	37	61	90	99

D. Humidex

Humidex is a validated measure for excess heat and humidity. It involves the calculation of vapour pressure that incorporated both indoor temperature and relative humidity measurements. We calculated Humidex based on the Environment Canada report (Masterton and Richardson 1979):

$$H = T + \frac{5}{9} \times (e - 10)$$

where H = Humidex, T = Temperature (°C), and e = vapour pressure (mb)

We calculated saturation vapour pressure based on Clausius-Clapeyron equation (Wallace and Hobbs 2006):

$$e_s(T) = e_s(T_0) \times exp\left(\frac{M_v L}{R_v}\left(\frac{1}{T_0} - \frac{1}{T}\right)\right)$$

where $e_s(T)$ is the saturation vapour pressure at temperature T (in °K), $e_s(T_0)$ is saturation vapour pressure at a reference temperature, T_0. The reference temperature and saturation vapour pressure used were T_0 = 273.15°K and $e_s(T_0)$ = 6.11 mb. The molecular weight of water and the gas constant for water vapour used were M_v = 18.016 g/mol and $R_v = 8.3144 \times 10^7$ erg/mol/°K (Masterton and Richardson 1979). L is the latent heat of evaporation for water (cal/g) (1 cal = 4.184×10^7 ergs) derived from a formula for typical environmental temperature ranges from 0 to 40°C (Fetter 2001):

$$L = 597.3 - 0.564T$$

Then we calculated the vapour pressure, e, using the relationship between saturation vapour pressure and relative humidity, RH.

$$e = e_s(T) \times \frac{RH}{100}$$

Humidex values (rounded to the nearest integer) were displayed within a matrix of typical indoor climate ranges (RH vs T) for visualising the cut-off point for “comfortable zone” as defined by Masterton and Richardson (1979).

Figure A 2. Humidex calculated as a function of indoor temperature and relative humidity

RH(%)																			
	100	22	24	25	27	29	31	33	35	37	39	41	43	45	47	50	52	54	57
	95	22	23	25	27	28	30	32	34	36	38	40	42	44	46	48	51	53	55
	90	21	23	24	26	28	29	31	33	35	37	39	41	43	45	47	49	52	54
	85	20	22	24	25	27	29	30	32	34	36	38	40	42	44	46	48	50	53
	80	20	22	23	25	26	28	30	31	33	35	37	39	41	43	45	47	49	51
	75	19	21	22	24	26	27	29	31	32	34	36	38	40	42	44	46	48	50
	70	19	20	22	23	25	27	28	30	31	33	35	37	39	40	42	44	46	48
	65	18	20	21	23	24	26	27	29	31	32	34	36	37	39	41	43	45	47
	60	18	19	21	22	24	25	27	28	30	31	33	35	36	38	40	42	44	45
	55	17	19	20	21	23	24	26	27	29	30	32	34	35	37	39	40	42	44
	50	17	18	19	21	22	24	25	27	28	30	31	33	34	36	38	39	41	43
	45	16	18	19	20	22	23	24	26	27	29	30	32	33	35	36	38	40	41
	40	16	17	18	20	21	22	24	25	26	28	29	31	32	34	35	37	38	40
	35	15	16	18	19	20	21	23	24	25	27	28	30	31	32	34	35	37	38
	30	15	16	17	18	20	21	22	23	25	26	27	29	30	31	33	34	36	37
	25	14	15	16	18	19	20	21	23	24	25	26	28	29	30	31	33	34	36
	20	14	15	16	17	18	19	21	22	23	24	25	27	28	29	30	32	33	34
	15	13	14	15	16	17	19	20	21	22	23	24	26	27	28	29	30	31	33
	10	13	14	15	16	17	18	19	20	21	22	23	24	26	27	28	29	30	31
	5	12	13	14	15	16	17	18	19	20	21	22	23	25	26	27	28	29	30
		17	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**T(°C)**

Green area: discomfort, white area: comfort (Masterton and Richardson 1979)

Table A 11. Humidex related to comfort.

Range of Humidex		Degree of comfort
20-29		Comfortable
30-39		Varying degrees of discomfort
40-45		Almost everyone uncomfortable
≥46		Many types of labour must be restricted

(Masterton and Richardson 1979)

E. Material Wellbeing Index – deriving the percentile rank

The graph below is provided by the Ministry of Social Development (Perry 2017). It shows where a given score ranks a household on the MWI distribution. For example, a score of 25 ranks the household at the 42nd percentile, or the household is above 42% of other households in New Zealand.

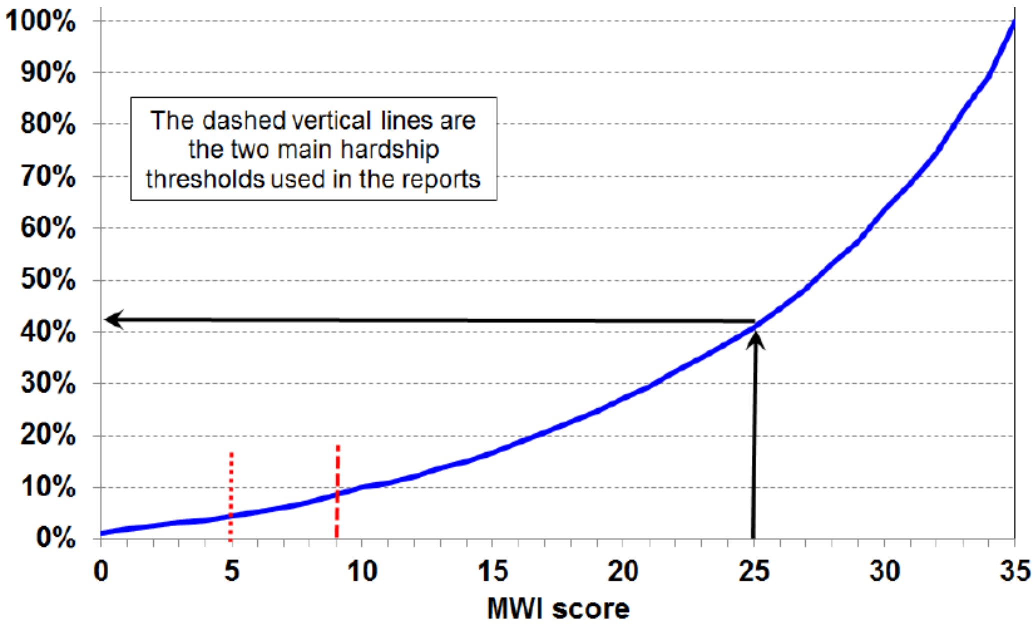


Figure A 3. Material Wellbeing Index scores and percentile rank in New Zealand
(Source: Ministry of Social Development 2017)

We extracted data points from the curve in the above figure and then empirically derived an equation (R^2=0.9993) to estimate the percentile rank (y-axis in the above) directly from the actual MWI score (x-axis in the above):

$$P = 1.811635 - \left(\frac{-0.4938022}{-0.08021269}\right) \times (1 - e^{0.08021269\,a})$$

where P is the percentile rank and a is the actual MWI score (in a converted range of 0 to 35)

F. Optimal cut-off points on Humidex

Humidex values (rounded to the nearest integer) were calculated using theoretical values of temperature and relative humidity that reflect typical indoor climate ranges. They were displayed in matrix for visualising the cut-off points determined by the optimal models in this study.

RH(%)	**100**	22	24	25	27	29	31	33	35	37	39	41	43	45	47	50	52	54	57	
	95	22	23	25	27	28	30	32	34	36	38	40	42	44	46	48	51	53	55	
	90	21	23	24	26	28	29	31	33	35	37	39	41	43	45	47	49	52	54	
	85	20	22	24	25	27	29	30	32	34	36	38	40	42	44	46	48	50	53	
	80	20	22	23	25	26	28	30	31	33	35	37	39	41	43	45	47	49	51	
	75	19	21	22	24	26	27	29	31	32	34	36	38	40	42	44	46	48	50	
	70	19	20	22	23	25	27	28	30	31	33	35	37	39	40	42	44	46	48	
	65	18	20	21	23	24	26	27	29	31	32	34	36	37	39	41	43	45	47	
	60	18	19	21	22	24	25	27	28	30	31	33	35	36	38	40	42	44	45	
	55	17	19	20	21	23	24	26	27	29	30	32	34	35	37	39	40	42	44	
	50	17	18	19	21	22	24	25	27	28	30	31	33	34	36	38	39	41	43	
	45	16	18	19	20	22	23	24	26	27	29	30	32	33	35	36	38	40	41	
	40	16	17	18	20	21	22	24	25	26	28	29	31	32	34	35	37	38	40	
	35	15	16	18	19	20	21	23	24	25	27	28	30	31	32	34	35	37	38	
	30	15	16	17	18	20	21	22	23	25	26	27	29	30	31	33	34	36	37	
	25	14	15	16	18	19	20	21	23	24	25	26	28	29	30	31	33	34	36	
	20	14	15	16	17	18	19	21	22	23	24	25	27	28	29	30	32	33	34	
	15	13	14	15	16	17	19	20	21	22	23	24	26	27	28	29	30	31	33	
	10	13	14	15	16	17	18	19	20	21	22	23	24	26	27	28	29	30	31	
	5	12	13	14	15	16	17	18	19	20	21	22	23	25	26	27	28	29	30	
		17	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	T(°C)

Green area: poorer indoor climate range defined by the optimal Humidex model in this study.
White area: optimal indoor climate range defined by the optimal Humidex model in this study.

Figure A 4. Cut-off points of Humidex based on the optimal model (<21, >28)

RH(%)																		
100	22	24	25	27	29	31	33	35	37	39	41	43	45	47	50	52	54	57
95	22	23	25	27	28	30	32	34	36	38	40	42	44	46	48	51	53	55
90	21	23	24	26	28	29	31	33	35	37	39	41	43	45	47	49	52	54
85	20	22	24	25	27	29	30	32	34	36	38	40	42	44	46	48	50	53
80	20	22	23	25	26	28	30	31	33	35	37	39	41	43	45	47	49	51
75	19	21	22	24	26	27	29	31	32	34	36	38	40	42	44	46	48	50
70	19	20	22	23	25	27	28	30	31	33	35	37	39	40	42	44	46	48
65	18	20	21	23	24	26	27	29	31	32	34	36	37	39	41	43	45	47
60	18	19	21	22	24	25	27	28	30	31	33	35	36	38	40	42	44	45
55	17	19	20	21	23	24	26	27	29	30	32	34	35	37	39	40	42	44
50	17	18	19	21	22	24	25	27	28	30	31	33	34	36	38	39	41	43
45	16	18	19	20	22	23	24	26	27	29	30	32	33	35	36	38	40	41
40	16	17	18	20	21	22	24	25	26	28	29	31	32	34	35	37	38	40
35	15	16	18	19	20	21	23	24	25	27	28	30	31	32	34	35	37	38
30	15	16	17	18	20	21	22	23	25	26	27	29	30	31	33	34	36	37
25	14	15	16	18	19	20	21	23	24	25	26	28	29	30	31	33	34	36
20	14	15	16	17	18	19	21	22	23	24	25	27	28	29	30	32	33	34
15	13	14	15	16	17	19	20	21	22	23	24	26	27	28	29	30	31	33
10	13	14	15	16	17	18	19	20	21	22	23	24	26	27	28	29	30	31
5	12	13	14	15	16	17	18	19	20	21	22	23	25	26	27	28	29	30
	17	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34** T(°C)

Green area: poorer indoor climate range defined by the optimal Temperature-Humidex model in this study.
White area: optimal indoor climate range defined by the optimal Temperature-Humidex model in this study.

Figure A 5. Combined cut-off points of Temperature-Humidex based on the optimal model (Temperature <19°C, Humidex >28)