Field Study of Summer Indoor Thermal Environment of School Buildings with Different Building Envelopes, Structures and Partitions

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Background

The redevelopment of Avondale College from 2010 to 2014 (design by Jasmax) represented one of the biggest school rebuilding programs in New Zealand's history. The project provides the school's 2750 students with 92 new and refurbished teaching and resource spaces. It is the first time that Thermomass precast concrete insulated panels (thermal mass) have been used as the main structure and building envelope of a new two-storey school building. Other one or two-storey, new or refurbished buildings in Avondale College are conventional lightweight timber frame construction with internal insulation and external cladding. With Unitec internal research funding and Jasmax's support, the previous field study of winter indoor thermal environment related to students' thermal comfort and health was carried out during 2013 - 2014. After the previous winter field study was published in the journals [1,2], this field study of summer indoor thermal environment related to students' thermal comfort was funded by Jasmax, Nauhria and New Zealand Ministry of Education. One of architectural master student was employed a research assistant for supporting this field study.

Introduction

The previous study showed that winter indoor thermal environment of a classroom with thermal mass in its building are better than the classroom without thermal mass, which is not only related to students’ thermal comfort but also to their health. This study used the summer field study data to compare and evaluate indoor thermal environment of the school buildings with or without thermal mass in their structures, envelopes, and partitions under the local climate. The first-time field study of summer indoor thermal environment of classrooms with or without thermal mass in their building structures, envelopes and partitions were carried out during the summer from 2015 to 2016 in Avondale College. As several important data loggers were damaged by the students, the inadequate data cannot be used for this study. The second-time field study of summer indoor thermal environment were carried out during the summer from 14 December 2017 to 12 March 2018. About 539,136 indoor and outdoor temperature and relative humidity data are collected in the field study.

Research Method

The field study of summer indoor microclimate of several classrooms with or without thermal mass in their building structures, envelopes and partitions were carried out in the Avondale College during the summer months. Indoor air temperatures and relative humidity near the ceiling and the floor of the sample classrooms and outdoor air temperature and relative humidity under the eaves of the roofs were continuously measured at 15-minute intervals 24 hours a day by HOBO temperature and relative humidity (RH) loggers. This study mainly used percentages of summertime related to different ranges of indoor mean air temperature to compare and evaluate summer indoor thermal environment of classrooms with different thermal mass in their buildings, especially when the temperatures are lower than 25 °C or 26 °C, the summer comfort zone for Auckland according to previous studies and the thermal standard [3-9]. During the summer term, the indoor thermal environment of classrooms can be strongly impacted or overruled by opening windows, using ceiling fans and the occupants' heat gain. This study only used the field study data during the team break without those factors to compare indoor potential thermal comfort of different classrooms purely impacted by their building summer thermal performance.

Research Method

The field study data of three types of classrooms with North orientation (two classrooms for each type) were used for this study.

New Classroom A21 & A39 in the middle of two-storey building), A21 (downstairs), A39 (upstairs)
Structure: Lightweight Timber Frame
Roof: Steel roofing (R 3.2)
Wall: Wetherboard / **Break Veneer** / LCP (R 2.2)
Floor: A21-**Precast concrete floor** (R 1.5)
A39-**Floor concrete slab**
Ceiling: A21-**Floor concrete slab**
Partition: Lightweight
Window and Door: Double glazing

New Classroom D16 & D21 in the middle of two-storey building, A16 (downstairs), D21 (upstairs)
Structure: **Precast concrete insulated panel**
Roof: Steel roofing (R 3.2)
Wall: **Precast concrete insulated panel** (R 1.5)
Floor: D16-**Precast concrete floor** (R 1.5)
D21-**Floor concrete slab**
Ceiling: D16-**Floor concrete slab**
Partition: **Precast concrete panel**
Window and Door: Double glazing

Retrofitted Classroom D8 & D9 in the middle of one-storey building
Structure: Lightweight Timber Frame
Roof: Steel roofing (R 3.2)
Wall: LCP laminate cladding panel (R 2.2)
Floor: Timber floor (R 1.5)
Partition: Lightweight
Window and Door: Double glazing

Data Analysis

Table 1 Mean air temperatures and percentage of summertime related to different ranges of indoor temperatures of 6 sample classrooms

Classrooms	A21 (downstairs)	A39 (upstairs)	D16 (downstairs)	D21 (upstairs)	D8	D9	Outdoor
Mean T (°C)	**24.9**	**25.3**	**23.4**	**24.5**	**25.0**	**25.1**	**22.7**
STDEV (°C)	**1.2**	**1.4**	**1.0**	**1.4**	**2.3**	**2.3**	**2.6**
Max T (°C)	**28.4**	**28.8**	**26.1**	**27.8**	**30.3**	**30.6**	**31.3**
Min T (°C)	**22.3**	**21.8**	**20.9**	**20.8**	**19.0**	**19.1**	**16.2**
Fluctuation (°C)	**6.1**	**7.0**	**5.2**	**7.0**	**11.3**	**11.4**	**15.1**
% Time T ≥18 °C	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**98%**
% Time T ≥25 °C	**44%**	**56%**	**8%**	**34%**	**49%**	**51%**	**19%**
% Time T ≥26 °C	**20%**	**31%**	**0%**	**15%**	**34%**	**36%**	**12%**
% Time T ≥27 °C	**7%**	**13%**	**0%**	**5%**	**20%**	**22%**	**7%**
% Time T ≥28 °C	**1%**	**4%**	**0%**	**0%**	**12%**	**12%**	**3%**
% Time T ≥29 °C	**0%**	**0%**	**0%**	**0%**	**5%**	**6%**	**1%**
% Time T ≥30 °C	**0%**	**0%**	**0%**	**0%**	**0.3%**	**0.7%**	**0.3%**

Fluctuation of indoor temperature of Classrooms D8 & D9 without thermal mass are significantly larger than Classrooms A21, A39, D16 and D21 with thermal mass, which can result very high indoor air temperatures during the summer.

The mean temperatures of Classroom A39 in upstairs is 0.4 °C higher than Classroom A21 in downstairs. The mean temperatures of Classroom D21 in upstairs is 1.1 °C higher than Classrooms D16 in downstairs.

Mean temperatures of Classrooms D16 and D21 with thermal mass are only 0.6 °C to 1.7 °C lower than Classrooms D8 and D9. The mean air temperatures of Classrooms A21 and A39 with limited thermal mass are close to Classrooms D8 and D9.

Data Analysis

Classrooms D16 & D21 with thermal mass in its structure, walls, floor (D21), Ceiling & Floor (D16) and Partition.

Classroom D8 & D9 without thermal mass in its building

To compare potential summer thermal comfort of classrooms with thermal mass (D16, D21) and without thermal mass (D8, D9) in their buildings:

- **With the same external surface areas (roof, north and south walls), the upstairs classroom D21 with thermal mass in its structure, wall, floor, and partition has 19% to 21% more summertime (more than 17.1 to 18.9 days) than Classrooms D8 and D9 without thermal mass in their building when indoor temperatures are lower than 25 °C (in comfort zone), and has 15% to 17% more summertime (13.5 days to 15.3 days) than Classrooms D8 and D9 when indoor air temperatures are lower than 26 °C (in comfort zone).**
- **With less external surface areas (north and south walls), the downstairs classroom D16 with thermal mass in its structure, ceiling, wall, floor, and partition has 41% to 43% more summertime (36.9 days to 38.7 days) than Classrooms D8 and D9 without thermal mass in their building when indoor temperatures are lower than 25 °C (in comfort zone), has 34% to 36% more summertime (30.5 days and 32.4 days) when indoor temperatures are lower than 26 °C (in comfort zone).**

Data Analysis

Classroom A21 & A39 with thermal mass in its wall (A21), floor and ceiling (A21) and floor (A39)

Classroom D8 & D9 without thermal mass in its building

To compare classrooms with limited thermal mass and without thermal mass in their buildings:

With limited thermal mass in the ceiling, floor, or wall, fluctuations of indoor temperature of Classrooms A21 and A39 (6.1-7.0°C) are significantly smaller than Classrooms D8 and D9 (11.3-11.4°C), which can prevent or reduce the very high indoor air temperatures. Although, there are not significantly difference of summertime between those classrooms when indoor temperatures are less than 25°C, Classrooms A21 and A39 has less summertime than Classrooms D8 and D9 when indoor temperatures are higher than 26°C. There are 5 to 6% summertime for Classrooms D8 and D9 when indoor mean temperatures are higher than 29 °C. Indoor mean temperatures of Classrooms A21 and A39 are never higher than 29 °C.

Conclusion and Discussion

According to the field study data during the term break, without impact of natural ventilation (opening window), mechanical ventilation (using ceiling fans) and occupants’ heat gain (without students), the summer thermal performance of a school building with thermal mass in its structure, wall, floor, and partition is significantly better than a conventional school building without thermal mass under the local climate. With the same insulation level according to the current building code, a classroom with thermal mass in its structure, wall, floor, and partition has 19% (17.1 days) more summertime than the conventional classroom without thermal mass when indoor temperatures are lower than 25°C (within the summer comfort zone) or has 15% (13.5 days) more summertime than the conventional classroom when indoor temperatures are lower than 26°C (within the summer comfort zone).

Fluctuations of indoor temperature of the classrooms (6.1-7.0°C) with limited thermal mass in their building are significantly smaller than the classrooms (11.3-11.4°C) without thermal mass, which can prevent or reduce the very high indoor air temperatures during the summer. Although, there are not significantly difference of summertime between those classrooms when indoor temperatures were less than 25 C°, the classrooms with limited thermal mass have less summertime than the classrooms without thermal mass when indoor temperatures were higher than 26 °C. Generally, limited thermal mass in a school building can still positively impact summer indoor thermal environment.

Conclusion and Discussion

Findings of this study can draw architects' attention to the relationship between summer indoor environment quality and school building design. The findings can be used as a general guide or strategy for retrofitting old school building or potentially for other types of buildings with the similar size (two-story), such as a library, an office building and a small commercial building mainly occupied during daytime for the temperate climate with warm, dry summer and mild, wet winter.

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Thank You!