World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:9, No:2, 2015

Field Study for Evaluating Winter Thermal Performance of Auckland School Buildings

Bin Su

Abstract**—**Auckland has a temperate climate with comfortable warm, dry summers and mild, wet winters. An Auckland school normally does not need air conditioning for cooling during the summer and only needs heating during the winter. The Auckland school building thermal design should more focus on winter thermal performance and indoor thermal comfort for energy efficiency. This field study of testing indoor and outdoor air temperatures, relative humidity and indoor surface temperatures of three classrooms with different envelopes were carried out in the Avondale College during the winter months in 2013. According to the field study data, this study is to compare and evaluate winter thermal performance and indoor thermal conditions of school buildings with different envelopes.

Keywords**—**Building envelope, Building mass effect, Building thermal comfort, Building thermal performance, School building.

I. Introduction

AVONDALE College opened in 1945, having been originally designed as a US hospital base during World War 2, with the intention of it being used as a school at the war's end. From 2010 to 2014, the redevelopment of Avondale College represents one of the biggest school rebuilding programs in New Zealand's history. This project was funded by New Zealand government and internal school funding, and designed by Jasmax. This rebuilding project includes 92 new and refurbished classrooms and resource rooms. The high performance Thermomass insulted precast panels were used for the new Maths Building (see Fig. 1). The two-storey structure is shear wall to three sides made from precast, thermally insulated concrete panels, with an in-situ concrete frame to the fourth. The floors are slab on grade concrete at ground level, with a suspended concrete floor above. The concrete inside has been carefully insulated from the external environment and been kept largely exposed to the internal environment. It is the first time for Thermomass insulated precast panels to be used as the main structure and building envelope of a new building in a secondary school building in New Zealand.

Previous study shows that the Auckland schools significantly use more energy during the winter than summer. An Auckland school commonly includes a number of low-rise isolated buildings spread over a large site. Most Auckland schools have a number of low-rise isolated buildings with one to four classrooms in rows. Most classrooms have big external surface area which includes two sides or three sides of external walls and roof surface areas [1]. For this type of school buildings, the building envelope becomes the most important building element for building thermal performance and indoor thermal conditions. Fig. 2 shows the building model of Avondale College rebuilding project. Three classrooms with different envelopes in the Avondale College are selected for this study. The three classrooms include one new "heavyweight" classroom in the new Maths Building with precast insulated concrete panel walls, sufficient insulations (Floor: R1.5, Wall: R2.2, Roof 3.2) [2] and double glazed windows (see Fig. 1); one refurbished existing "lightweight" classroom with light rain screen walls, sufficient insulations (Floor: 2.6, Wall: R2.2, Roof: 2.9) [2] and double glazed windows in an one-storey building (see Fig. 3); and one old "lightweight" prefabricated and isolated classroom with minimum insulations (Floor: 0.9, Wall: 1.5, Roof: 1.9) [3] and single glazed windows, which have been on site since the early 1990s and demolished by the end of the project. Indoor air temperatures and relative humidity near ceiling and floor of the three classrooms and outdoor air temperature and relative humidity under the eaves of roof were continuously measured at 15-minute intervals 24 hours a day during the winter months in 2013. Indoor surface temperatures of ceiling, floor, wall and window of the three classrooms were also measured during the winter day time.

Fig. 1 Maths Building with precast insulated concrete panel walls

Bin Su is Professor of Architectural Science, School of Architecture, Unitec Institute of Technology, Auckland, New Zealand and Visiting Professor, School of Architecture and Urban Planning, Shandong Jianzhu University, Jinan, China (phone: 0064-9-8154321 ext 7847; fax: 0064-9-8154343; e-mail: bsu@unitec.ac.nz).

Fig. 2 The building model of Avondale College rebuilding project

Fig. 3 One-story building with light rain screen wall

II. Method

The World Health Organisation recommends a minimum indoor temperature for houses of 18°C; and 20-21ºC for more vulnerable occupants, such as older people and young children [4], [5]. The current New Zealand Building Code does not have a general requirement for the minimum indoor air temperature, although it has a requirement of 16ºC for more vulnerable occupants, such as older people and young children [6], [7]. Winter indoor air temperatures, winter indoor mean air temperature 24-hours profiles, percentages of winter time when indoor air temperatures were higher than 16°C and differences between indoor and outdoor mean air temperatures of the three classrooms are used to for this study. This study is to use field study data to compare and evaluate thermal performance of classrooms with different envelopes under the same winter climatic conditions. The study is also to compare indoor thermal conditions of classrooms with or without thermal-mass in their envelopes at the similar insulation level, and indoor thermal conditions of "lightweight" classrooms with different insulation levels under the Auckland winter climatic conditions.

III. Field Study Data

A. Indoor Air Temperatures

During the winter months, indoor mean air temperatures of the classroom with precast insulated concrete panel walls are generally higher than classroom with light rain screen wall and the prefabricated and isolated classroom. Fluctuations of indoor air temperatures of the classroom with precast insulated concrete panel walls are smaller than the classroom with light rain screen wall and the prefabricated and isolated classroom (see Fig. 4). As indoor air temperatures are not only impacted by outdoor temperatures but also sun and space heating during the winter daytime, fluctuations of indoor air temperatures of the three classrooms during the winter daytime are larger than the winter night time (see Figs. 5, 6 and Tables I, II). During winter night time without space heating, indoor mean air temperatures of the classroom with precast insulated concrete panel walls are 2.8°C higher than classroom with light rain screen wall with the similar insulation level. During winter night time, indoor mean air temperatures of the classroom with light rain screen walls and sufficient insulation are 1.7°C higher than the prefabricated and isolated classroom with lower insulation level (see Table I).

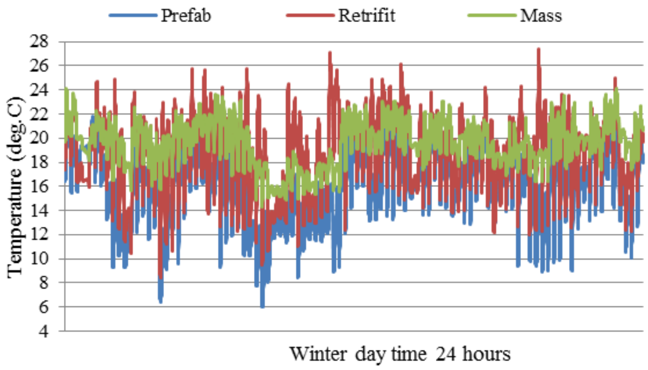

Fig. 4 Indoor air temperatures during the winter months

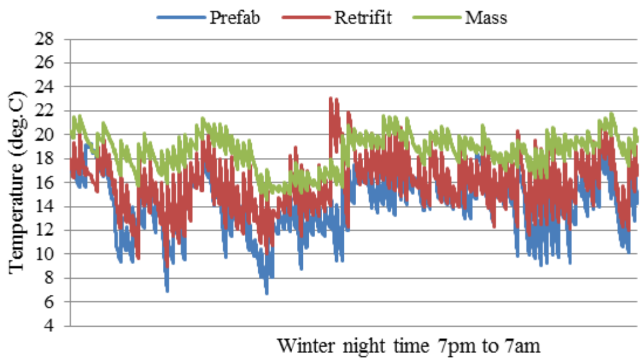

Fig. 5 Indoor air temperatures during the winter night time

For During winter daytime, indoor mean air temperatures of the classroom with precast insulated concrete panel walls are not significantly higher than the classroom with light rain screen wall as indoor mean air temperatures were influenced by solar radiation and space heating. As the light structure building envelope is heated up quickly and also cooled down quickly, fluctuations of indoor air temperatures of the classroom with light rain screen wall (18.9°C) are significantly bigger than the classroom with precast insulated concrete panel walls (9.8°C). Indoor maximum air temperature of the classroom with light rain screen wall can reach to 27°C during the winter daytime, which could cause "over heating" during school hours. For the classroom with precast insulated concrete panel walls, indoor maximum air temperature is 24°C and more stable than light structure envelope when the space heating is used.

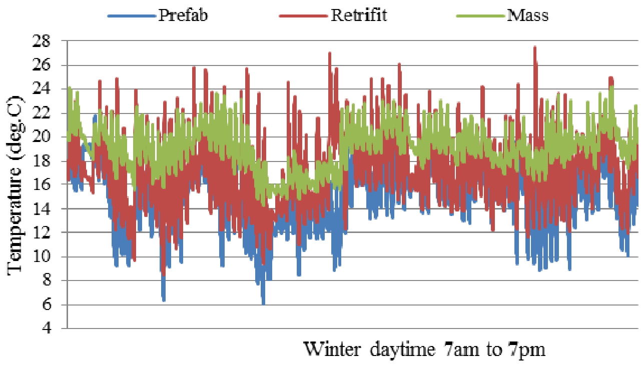

Fig. 6 Indoor air temperatures during the winter daytime

TABLE I
INDOOR TEMPERATURES DURING WINTER NIGHT TIME

Night time	Prefab	Retrofit	Mass	Outdoor
Mean indoor temperature	14.1°C	15.8°C	18.6°C	10.7°C
Difference of indoor / outdoor	3.4°C	5.1°C	7.9°C	
Maximum indoor temperature	19.5°C	23.1°C	21.7°C	17.7°C
Minimum indoor temperature	6.7°C	9.0°C	14.6°C	2.0°C

TABLE II
INDOOR TEMPERATURES DURING WINTER DAYTIME

Daytime	Prefab	Retrofit	Mass	Outdoor
Mean indoor temperature	15.8°C	18.8°C	19.5°C	13.7°C
Difference of indoor / outdoor	2.1°C	5.1°C	5.8°C	
Maximum temperature	22.0°C	27.4°C	24.2°C	20.6°C
Minimum temperature	6.0°C	8.5°C	14.3°C	1.9°C

B. Indoor Mean Air Temperature 24-Hours Profile

All field study data (see Fig. 4) of indoor and outdoor air temperatures have been converted into indoor hourly mean air temperatures during the winter months for comparing thermal performance of the three classrooms with different envelopes. Fig. 7 shows winter indoor mean air temperature 24-hours profiles of the three classrooms. Because of mass effect, winter indoor mean air temperature 24-hours profile of the classroom with precast insulated concrete panel walls is more stable and has less response to variation of outdoor temperatures than the classroom with light rain screen wall and the prefabricated and isolated classroom. During the winter months, indoor hourly mean air temperatures are always close to or higher than 18°C and significantly higher than the classroom with light rain screen wall and the prefabricated and isolated classroom especially for the night time and early morning in the absence of solar and space heating. During the early morning, indoor hourly mean air temperatures of the classroom with light rain screen wall can drop down to 14.1°C but the minimum hourly mean air temperature of the classroom with precast insulated concrete panel walls is 17.8°C (see Fig. 7).

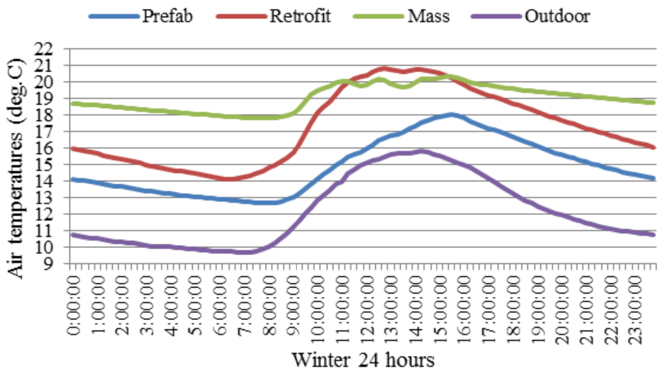

Fig. 7 Winter hourly mean air temperature 24-hours profile

C. Percentage of Time When Indoor Air Temperatures Are Higher than 16°C

All field study data of indoor and outdoor air temperature (see Fig. 4) have been converted into percentages of winter times when indoor air temperatures are equal or higher than 16°C for comparing indoor thermal comfort conditions of the classrooms with different envelopes. For 94% of the winter time (see Table III), indoor air temperatures of the classroom with precast insulated concrete panel walls are equal or higher than 16°C, which is significantly higher than the classroom with light rain screen walls (64.2%) and the prefabricated and isolated classroom (37.9%). Within 94% of winter time, the distribution of indoor air temperatures of the classroom with precast insulated concrete panel walls is between 16°C to 24°C, which is more stable than the classroom with light rain screen walls. Within 64.2% of winter time, the distribution of indoor air temperatures of the classroom with light rain screen walls is between 16°C to 26°C. About 36% of winter time mainly from middle night to 9am, indoor air temperatures of the classroom with light rain screen walls are lower than 16°C (see Fig. 7 and Table III). The classroom with "heavyweight" envelope has more comfort and stable indoor thermal conditions than the classroom with "lightweight" envelope. For the "lightweight" envelope with different insulations, the classroom with light rain screen walls can increase 26% of winter time, when indoor air temperatures are higher 16°C, to compare with the prefabricated and isolated classroom. Within 37.9 % of winter time, the distribution of indoor air temperatures of the prefabricated and isolated classroom is between 16°C to 20°C. Over 95% of winter school hours from 8:30 am to 3:30 pm with space heating, indoor air temperatures of the classroom with precast insulated concrete panel walls are equal or higher than 16°C, which is higher than the classroom with light rain screen walls (84.8%) and the prefabricated and isolated classroom (51.7%). With similar insulation level and with permanent heating, the classroom with precast insulated concrete panel walls has more comfortable and stable indoor thermal conditions than the classroom with light rain screen walls during the winter school hours.

TABLE III
PERCENTAGE OF WINTER TIME WHEN INDOOR AIR TEMPERATURES ARE HIGHER THAN 16°C

Tem. ranges	≥16°C	≥18°C	≥20°C	≥22°C	≥24°C	≥26°C	Indoor Mean
Prefab	37.9%	15.9%	3.2%	0%	0%	0%	14.9
Retrofit	64.2%	40.2%	21.4%	7.3%	1.4%	0.2%	17.3
Mass	94.0%	75.0%	30.7%	3.6%	0%	0%	19.0

TABLE IV
PERCENTAGE OF SCHOOL HOURS WHEN INDOOR AIR TEMPERATURES ARE HIGHER THAN 16°C

Tem. ranges	≥16°C	≥18°C	≥20°C	≥22°C	≥24°C	≥26°C	Indoor Mean
Prefab	51.7%	27.4%	6.9%	0%	0%	0%	15.8
Retrofit	84.8%	70.7%	48.9%	20.5%	4.3%	0.5%	19.4
Mass	95.6%	81.2%	47.4%	9.8%	0%	0%	19.6

IV. CONCLUSION

According to the field study data, winter indoor mean air temperatures of the classroom with precast insulated concrete panel walls are significantly higher and more stable than the classroom with light rain screen wall and the prefabricated and isolated classroom. Mass effect of the classroom with precast insulated concrete panel walls can contribute 2.8°C of increasing indoor mean air temperature when the classroom has similar insulation level. During the early morning, low indoor air temperature of the "lightweight" classroom is a big challenge to control indoor thermal conditions for thermal comfort, which not only needs more heating energy but also takes time to heat up the space. The "heavyweight" classroom can significantly rise indoor minimum air temperature during the early morning and night time. Adding "mass" in a school building envelope with sufficient insulation can be a solution to increase indoor minimum temperature during the winter time for thermal comfort and energy efficiency. With similar insulation level and permanent heating, the classroom with precast insulated concrete panel walls has more comfortable and stable indoor thermal conditions than the classroom with light rain screen walls during the winter school hours. The light structure envelope with high insulation level can potentially cause over heat problem if the permanent space heating is not automatically controlled.

REFERENCES

[1] B. Su, "Impacts of Building Design Factors on Auckland School Energy Consumptions." *World Academy of Science, Engineering and Technology, International Journal of Civil Science and Engineering*, Vol.7, no.12, pp. 278-384, 2013.

[2] *SNZ, "New Zealand Standard 4218-2009 Thermal insulation: housing and small buildings."* Wellington, New Zealand: Standards New Zealand, 2009.

[3] SANZ, "*New Zealand Standard 4218p-1977 Minimum thermal insulation requirements for residential buildings*." Wellington, New Zealand: Standards Association of New Zealand, 1977.

[4] WHO, *"Air quality guidelines for Europe 2000 - Second Edition WHO Regional Publications."* European Series, N91, 2000.

[5] J. Sateru, "*Finnish Society of Indoor Air Quality and Climate, ISIAQ-CIB TG 42 Performance criteria of buildings for health and comfort.*" published by CIB secretariat, No 292, 2004.

[6] DBH, "*Compliance Document for New Zealand Building Code – Clause G5 Interior Environment*." Wellington, New Zealand: Department of Building and Housing, 2001.

[7] SANZ, "*New Zealand Standard 4303-1990 Ventilation for acceptable indoor air quality*." Wellington, New Zealand: Standards Association of New Zealand, 1990.