

Temperature Control & Comfort Level of Elementary School Building with Green Roof in New Taipei City, Taiwan

Ying-Ming Su, Mei-Shu Huang

Abstract—To mitigate the urban heat island effect has become a global issue when we are faced with the challenge of climate change. Through literature review, plant photosynthesis can reduce the carbon dioxide and mitigate the urban heat island effect to a degree. Because there are not enough open space and parks, green roof has become an important policy in Taiwan.

We selected elementary school buildings in northern New Taipei City as research subjects since elementary schools are asked with priority to build green roof and important educational place to promote green roof concept. Testo175-H1 recording device was used to record the temperature and humidity differences between roof surface and interior space below roof with and without green roof in the long-term. We also use questionnaires to investigate the awareness of comfort level of green roof and sensation of teachers and students of the elementary schools.

The results indicated that the temperature of roof without greening was higher than that with greening by about 2°C. But sometimes during noontime, the temperature of green roof was higher than that of non-green roof probably because of the character of the accumulation and dissipation of heat of greening. The temperature of the interior space below green roof was normally lower than that without green roof by about 1°C, showing that green roof could lower the temperature. The humidity of the green roof was higher than the one without greening also indicated that green roof retained water better.

Teachers liked to combine green roof concept in the curriculum, and students wished all classes can take turns to maintain the green roof. Teachers and students whose school had integrated green roof concept in the curriculum were more willing to participate in the maintenance work of green roof. Teachers and students who may have access to and touch the green roof can be more aware of the green roof benefit. We suggest architects to increase the accessibility and visibility of green roof, such as use it as a part of the activity space. This idea can be a reference to the green roof curriculum design.

Keywords—Comfort level, elementary school, green roof, heat island effect.

I. INTRODUCTION

THE rapid and high-density urbanization aggravates the urban heat island effect in the world. Researches showed that increasing the ratio of green cover, creating habitat for creatures and reducing carbon dioxide can effectively reduce heat island effect. In past decades, many experts and scholars started seeking how to increase the green space in the

high-density urban area? The easiest method is to develop into the high floors and increase the green roof area on top of the buildings, which is the green roof design. The United Nations Environment Program study showed that, when the covered rate of green roof can achieve 70%, the whole city's carbon dioxide will reduce by 80% [1], which has a positive contribution to purifying the urban air and elevating urban landscape.

Nowadays, it's a worthy policy to encourage the school buildings to construct green roofs because of their characteristics such as having the largest roof space, having educational implications, and easier to promote.

To determine the influence of green roof on cities, in this paper, the authors use extensive field measurements and questionnaires to investigate the comfort level at elementary school green roof. The measurement data include air temperatures and relative humidity. The results will establish a theoretical basis for students and teachers' cognition and feelings about the green roof space. Furthermore, the importance and benefits of green roof design are proven and the paper provides a reference for prospective planning.

II. BACKGROUND

A. Green Roof Research Theory

The research of green roof has become more and more important around the world because the global climate has changed and is threatening human residential area. A study proved that the wind velocity can affect the overall heat transfer at green roof combinations, and sensible heat fluxes have a very important role [2], [3]. Main parameters that affect indoor comfort and air conditioning energy consumption were examined, which included different vegetation, soil thickness and building roof type. A successful green roofs design can serve as surrogate thermal insulation to restrict heat from entering indoor space and save the building's energy consumption [4]-[6]. In summer, green roofs have effect on indoor environment cooling, which is more notable on hot summer days. They provide a thermal insulation layer to reduce the heat from outdoor solar radiation, which also results in energy conservation. In Subtropical regions, a research indicates that the green roof tends to have lower surface temperature than the original exposed roof surface, especially in areas well covered by vegetation. A maximum temperature difference of 18°C was observed [7], [8].

In terms of green roof facilities management and

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maintenance, the research points out that different social background would have different cognition of green roof management issues. Therefore, strengthen advocacy for environmental benefits of green roofs will help to improve the public awareness and raise support for the green roof [9]. On the other hand, the analysis of the survey results shows that the key factors influencing the maintenance performance of green roofs are cost of maintenance, level of student participation, type of vegetation, and level of openness [10].

B. The Environment Background Overview

The case study is completed in Wang Xi Elementary School of New Taipei City, Taiwan, where onsite measurements are conducted. The building of this study was altered into Green Building and obtained the Taiwan's EEWB award in 2012. Fig. 1 shows the school birds-eye view and green roof configuration. This building is 14m high with green roof and non-green roof facilities. The green roof is located on the terrace of the fourth roof and covers 160 m², below which are all classrooms. Its long axis goes toward the northeast, beneath which the classroom door opens to the northwest. In this study, extensive field measurements and questionnaires were used to investigate and compare the green roof and non-green roof thermal comfort level.



Fig. 1 Location and bird's-eye of Wang Xi Elementary School, Taiwan

C. The Type of Green Roof

Fig. 2 shows the form and configuration layout of the Wang Xi Elementary School green roof. We put raw clay and light soil above the waterproof layer, which makes the green roof high roof stratified type planting. The total covering depth is about 0.3m.



Fig. 2 The green roof configuration and environment images

III. METHODOLOGY

A. Field Measurements

The extensive experiments to measure the green roof and non-green roof were conducted on a 24-hour basis for three days from July to December, 2014 during the summer and winter. To cover all monitoring positions, the measuring instruments were relocated to green roof, non-green roof and under the roof to repeat the same experimental procedure for measurements of the temperature and relative humidity.

Fig. 3 shows the status of environment images of green roof, non-green roof and inside the classroom. The coordinates of 8 monitoring points, the numbers O represents an outdoor space, I refer to indoor, (G) represents green roof. For the sake of experimental accuracy, the principle is fixing the measuring points, and experimental data were measured at a 15 cm height (Fig. 4). In this study, the total air temperature and relative humidity were measured by a Testo175-H1 sensor. The related accuracy values of temperatures and relative humidity were within -20 to 55°C, respectively, in the measuring range of 0-100% RH. To avoid the effect of weather from causing measurement inaccuracy, the measuring period was at least 15 min long with the data recorded every 1 second for each point. Based on the above obtained data, we can evaluate the green roof effect on thermal comfort.

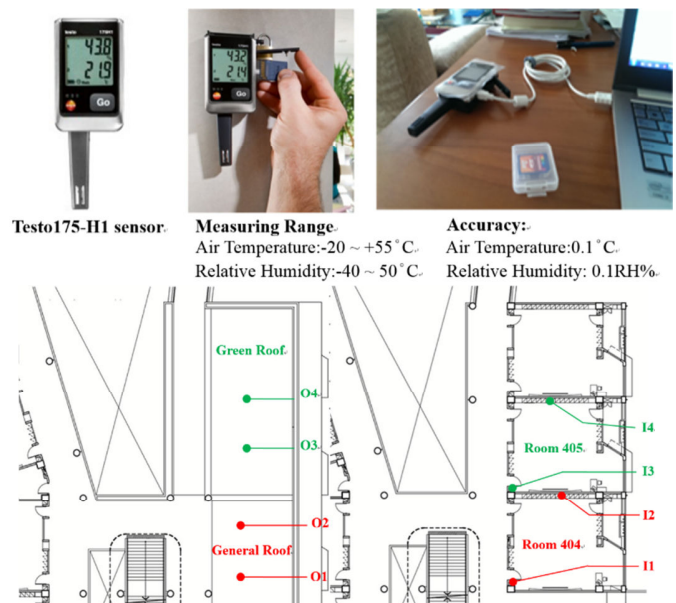


Fig. 3 Measuring instruments and setting point



Fig. 4 The measured points in green roof and interior classroom

B. Investigation Questionnaires

The questionnaire survey of the green roof was conducted from November to December 2014 during the class time. The objective of the questionnaire included Wang Xi Elementary School and Chong De Elementary School teachers and students. 45 questionnaires were collected from the teachers; 52 questionnaires were collected from the students who were using the classroom covered by green roof; 52 questionnaires were collected from the students who were using the classroom without green roof. A total of 149 effective questionnaires were collected in this study, among which the valid samples were 140 copies after excluding the invalid ones, accounting for 92% of the whole copies.

IV. RESULT AND ANALYSIS

In this research, the author first investigates site situation, arranges the monitoring points and measures the data, comparing it with the data from the weather station of the Central Weather Bureau in the recent decade. Subsequently, the result of field measurement data shows that the difference air temperature average and relative humidity values of the two monitoring points are within 0.18°C, and 1.8%RH. These data values are credible because the air temperatures and relative humidity of the measuring instrument lie in the accuracy error range of $\pm 0.4^\circ\text{C}$, and $\pm 2\% \text{RH}$. Therefore, the measured temperatures and relative humidity data will be averaged and used as the basic data for analysis and discussion.

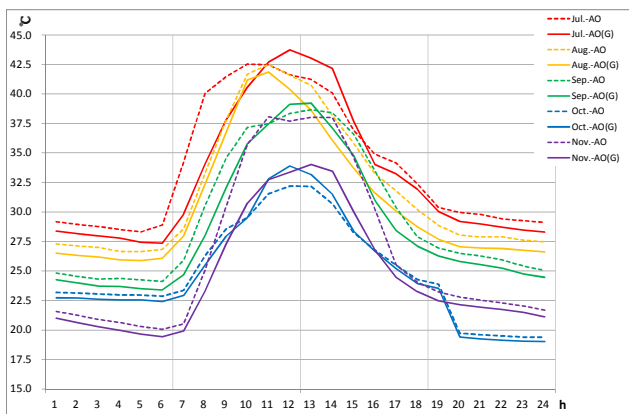


Fig. 5 Monthly hours result of the temperature in the green roof and non-green roof

We compare the green roof and non-green roof air temperature and relative humidity. The 5 times field measurement covered two typical seasons. The 24-hour measured data will be averaged hour by hour. During the analysis process, the Central Weather Bureau's same period

observation data of air temperature and relative humidity, wind speed, sunshine hours and other recorded material will be used to provide reference to the measured data.

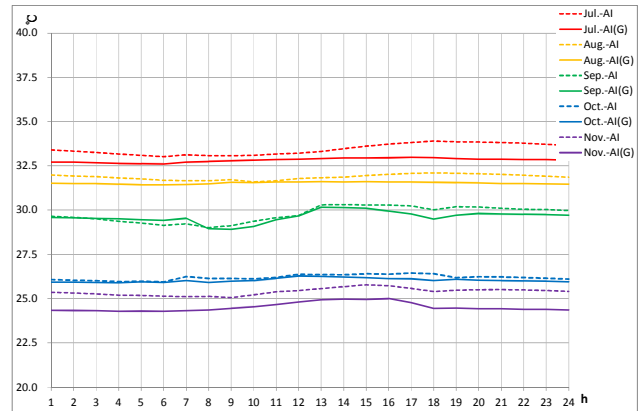


Fig. 6 Monthly hours result of the interior temperature in the green roof and non-green roof

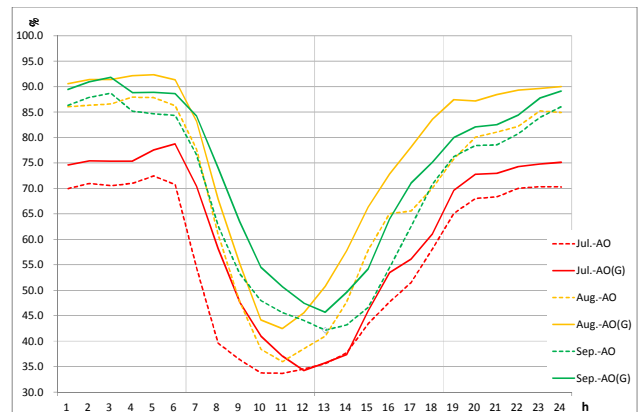


Fig. 7 Measured result of relative humidity in July to September

Figs. 5 and 6 show the comparison of the green roof air temperature and non-green roof air temperature. Figs. 7 and 8 show the comparison of the green roof humidity and non-green roof relative humidity.

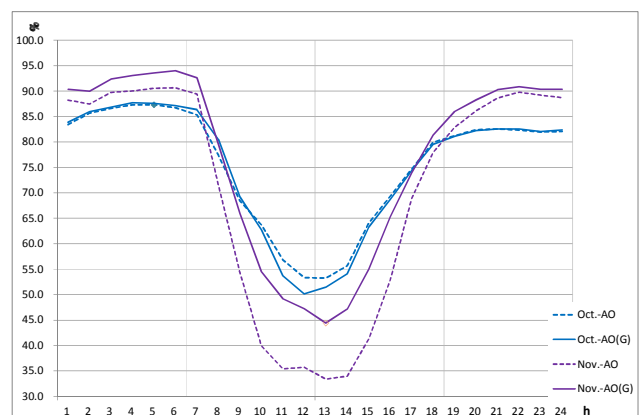


Fig. 8 Measured result of relative humidity in October to November

A. The Roof Temperature Analysis and Discussion

Fig. 9 shows the results of the air temperature. Non-green roof air temperature is generally higher than the green roof air temperature, but in July, September and October there is an opposite result. In the monthly result, the green roof air temperature in daytime is lower than the non-green roof air temperature, with a maximum difference around 5.93°C.

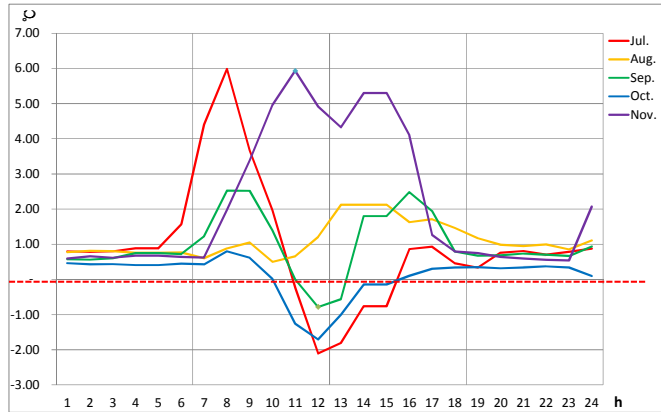


Fig. 9 Monthly hours result of the temperature difference in the green roof and non-green roof

B. The Indoor Temperature Analysis and Discussion

Fig. 10 shows the results of the interior air temperature. The non-green roof interior air temperature is generally higher than the green roof interior air temperature, but in September there is an opposite result—the measured green roof interior air temperature remained at almost the same level as non-green roof's temperature. As can be seen, the difference is small. In the monthly result, non-green roof interior air temperature is higher than green roof interior air temperature, but exception only occurred at 7:00 during September. The maximum and minimum results shows that the maximum interior air temperature difference is in November at 1.1°C, and the minimum interior air temperature difference is in September at 0.22°C.

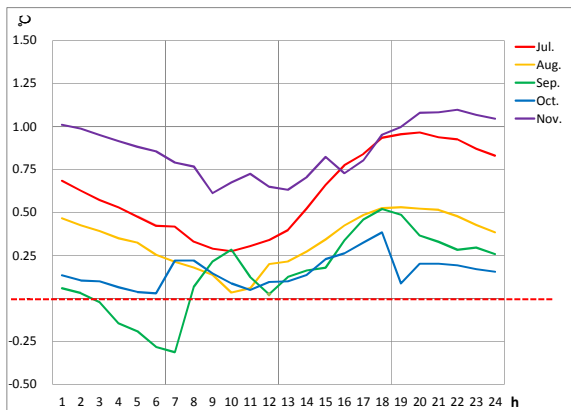


Fig. 10 Monthly hours result of the interior temperature difference in the green roof and non-green roof

C. The Outdoor Temperature Analysis and Discussion

Comparing the interior and outdoor air temperature, the

measured non-green roof interior air temperature remained at almost the same level as the outdoor green roof interior temperature. As can be seen, the difference is small. The maximum interior air temperature results shows that the non-green roof maximum interior air temperature difference is in November at 12.67°C, and the green roof interior air temperature difference is in July at 10.85°C. The result shows that green roof can provide an insulation layer to reduce solar radiation heat getting into the interior. Fig. 11 shows the monthly results of the interior and outdoor air temperature. The green roof interior air temperature is generally lower than the non-green roof interior air temperature, with a maximum difference of 2.6 °C. During the day time, the larger difference is between the green roof interior and non-green roof air temperature, and the smaller difference is between that of the green roof interior and non-green roof.

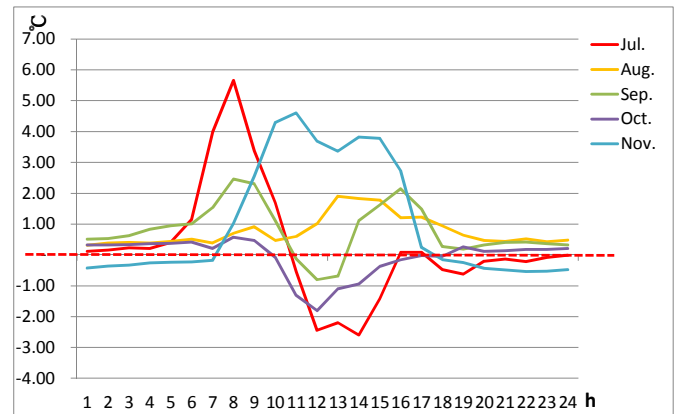


Fig. 11 Monthly hours result of the temperature difference in the interior and outdoor space

D. The Roof Relative Humidity Analysis and Discussion

Non-green roof relative humidity is generally lower than that of the green roof in the daytime, but in October there is an opposite result, with the trends roughly inverting the relationship. In the monthly result, the green roof and non-green roof relative humidity difference was irregular, with maximum about 18.57% and a minimum 11.35% (as Fig. 12).

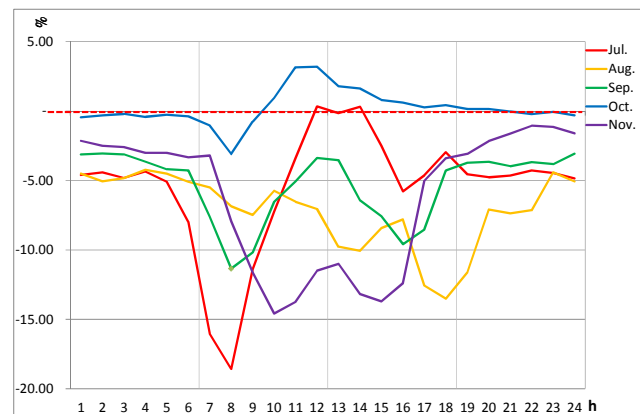


Fig. 12 Monthly hours result of the relative humidity difference in the interior and outdoor space

E. Air Temperature and Relative Humidity with Human Comfort Discussion

Based on the definition of human comfort, main parameters that affect human comfort are noise, sunshine, air temperature, air quality and relative humidity. The paper aims at presenting the results coming from the comparison of air temperature and relative humidity, which have effect on indoor human comfort. In meteorology, humidity typically refers to air humidity, which is the water vapor content in the air. High air temperatures have high capacities for accommodating water vapor. This research refers to the Central Weather Bureau weather station and maintains air temperature and relative humidity comfort level between 20-26°C, and 40-60%.

V. RESULTS OF SURVEY AND ANALYSIS

A. Survey the Degree of Cognition of the Green Roof and Ecological Sustainability of the Teacher

On the degree of cognition at the green roof and ecological sustainability of the teacher, there are nine topics. The degree of cognition of each question have Do not agree (1 point), Not agree (2 point), General (3 point), Agree (4 point), Very Agree (5 point). Survey results showed the teacher most agree on the "Green roofs can improve the air quality and clean air" (4.8 point), and "Green roofs can decrease the indoor temperature in the summer" (4.7 point).

B. Survey the Degree of Cognition of Green Roofs on Visual, Psychological and Educational Benefits Feelings and Personal Preferences of the Teacher

On the degree of cognition of the green roof and visual psychology and education of the teacher, there are two topics on visual psychology, and three topics on education. The degree of cognition of each question has five scores. Survey results showed the teachers most agree on the "Make the green roofs landscaping can increase visual pleasure", and "Green roofs can provide opportunities for education as well as teaching space and material".

C. Survey the Degree of Cognition of the Green Roof and Feeling about Personal Preferences of the Student

To understand the extent of student recognition and preferences of green roof, first, survey and count the "There is a green roof above my classroom", and the students which their classrooms are located beneath the green roof accounted for 51.8% of all students (among them students who know the green roof above the classroom accounted for 71%, but there are still students who do not know the green roof above the classroom, accounting for 29%). The students who are not in the classroom with a green roof account for 48.2% (among them students who know the green roof above the classroom accounted for 62%, but students who still do not know the green roof above the classroom accounted for 38%).

The degree of cognition has eight topics, and personal preferences have four topics. The grading respectively: Not, or do not like (1 point), General or have no opinion (3 point), Yes or like (5 point). Survey results show that the students most agree on "Green roofs make me feels that the air is cleaner",

and the part of personal preferences is "I like the school setting a green roof".

D. Survey the Relation between the Green Roof and Gender to Support the Teachers and Students

A total of 104 people consisting of teachers and students have been surveyed, among whom there are 83 people (79.8%) supporting and enjoying green roofs. 42 of these people are women and 41 are men. There are 4 people (3.8%) who do not support or enjoy green roofs, among whom 2 people are women and 2 are men. 17 people (16.4%) didn't answer, among them 6 people were women and 11 were men.

E. Survey the Relation between the Green Roof and Maintenance Management to Support the Relation of the Teachers and Students

For the relation between the green roof and maintenance management to support the relation of the teacher and student, surveyed results showed that 95.1% teachers expressed that they supported the school to set the green roof, while 3.3% of them expressed that they did not support, and the other 1.6% didn't give any opinion. The main reason for not supporting the green roof was leaking problems and increasing difficulty and cost on maintenance management of the school. 72.3% of students expressed that they supported the school to set the green roof, while 4.3% of them expressed that they did not support, and the other 23.4% didn't give any opinion.

F. Survey Suggestion of the Green Roof Maintenance Management of the Teachers and Students

According to the visit, the general school services Department is in charge of the green roof maintenance management, but the community volunteers of Wang Xi Elementary School mainly does the maintenance and planting, and the maintenance management of Chong De Elementary School is done by the school volunteers and other teachers. And according to surveys of who should be responsible for the maintenance and management of green roofs, 33.3% respondents of teacher hope the curriculum could include the maintenance management of green roofs, and let teacher lead students to do the maintenance management of green roofs. 28.9% respondents of teachers hope the professionals could do the maintenance management. Most students, about 26.3%, hope to take turns to do the maintenance management in class, and 22.4% respondents of students hope the curriculum could include the maintenance management of green roofs, and let teachers lead students to do the maintenance management of green roof.

G. Survey the Degree of Favor of the Teacher and Student to the Green Roofs in Each Case

The space planning in the design of the green roof on Wang Xi Elementary School is not limited to a particular location. The green roof designers planned to flinch at the number above the second floor terrace, and making the green roof blend into the student activity space could add to great availability and visibility. Through the surveys and field observations, when the climate is pleasant, students like reading and playing around the

green roof and it greatly improves teachers' and students' feelings. For the cases of the old campus promoting green roofs in the public office, the most important point in designing a green roof on Wang Xi Elementary School is a proper installation position. We expect to provide reference for green roof designers and help improve the future policy through The design in this case.

Although the green roof of Chong De Elementary School is refurbished from the old building, we change the existing roof into a garden and include learning ecological education in the program. We can find the results from the survey that green roofs are loved by both teachers and students. They like learning and doing activities on green roofs, and this is a success case of blending the green roofs into the curriculum.

VI. CONCLUSION

A. The Influence on Interior and Outdoor Air Temperature and Relative Humidity of Setting the Green Roof

1) Green Roof Can Achieve Cooling Effect and Mitigate Urban Heat Island Effect

The research shows that the non-green roof air temperature is generally higher than the green roof air temperature during the daytime, and a maximum temperature difference of 5.93°C was observed. But sometimes the green roof temperature was higher than non-green roof's temperature, with a 0.56°C difference. At night and in the early morning, the heat quickly dissipates and the air temperature difference was between 0.5 to 1°C. In the results, green roof design can increase water permeability and water retention on rainy days. Using the vegetation and water to absorb heat can mitigate urban heat island effect. On the other hand, the soil and planting species also affect heat storage and cooling effect.

2) Green Roof Can Improve Interior Cooling Effect

In the comparison of the non-green roof and green roof interior space air temperature, the non-green roof air temperature is generally higher than the green roof air temperature from July to November, and the average interior air temperature difference is 0.02-1.1°C. The result shows that green roof has a positive effect to lower the temperature.

3) Green Roof Design Can Reduce 2.86°C in the Roof Space

In the comparison of interior space and outdoor space result, the interior and outdoor air temperature was in control of the roof space. If we compare the time when the highest air temperature occurs on non-green roof and green roof, the air temperature on the green roof continued to decline from August to October. The green roof air temperature is lower than the non-green roof air temperature, with the maximum difference lying between -0.6 and 1.81°C. On the other hand, the different materials of green roof configuration, such as soil and vegetation will reflect the solar radiation heat and cause interior temperature to rise.

4) Green Roof Have Water Retention Effect

In the results of the non-green roof compared with green roof

relative humidity, green roof relative humidity is generally higher than non-green roof; green roof can increase 18 % relative humidity and provide water retention effect. During the daytime and night, the air temperature and relative humidity change inversely. In the monthly result, the green roof and non-green roof relative humidity difference is irregular, with maximum at about 18.57% and a minimum at 11.35%.

B. The Relationship between Green Roof and Human Comfort Level

In the comparison of the interior measured result and the observation data of the same period from the Central Weather Bureau, the result shows that the interior comfort level of green roof spaces is directly influenced by the seasonal effect. The average air temperature and relative humidity in the interior space are influenced by the local climate, and the green roof design's effect on the interior air temperature and relative humidity is relatively small but it has significant influence on urban heat environment.

C. The Degree of Cognition of Teachers' and Students' Feeling about Green Roofs

For the degree of cognition of teachers on green roofs and the benefits of ecological sustainability, the main cognition is that green roofs can reduce interior temperature and upgrade the air quality. But most of them do not understand that green roof can help isolate noise and prevent fire. For the visual and psychological view on green roofs, they thought landscaping of green roof can please the visual more than relieve stress and ease the mood. On the education perspective, they most agree that the green roof can increase opportunities for education as well as teaching space and material.

As for the degree of cognition of students on green roofs and feeling about green roofs, they most agree that the green roof can make the air cleaner. But they comparatively disagree that the green roof can let people feel warmer in winter, and feel cooler in summer. For personal preference, they support school setting green roofs, but they do not want to spend the time taking care of the green roof.

The teachers and students who support and like green roofs account for 79.2%, while people who do not like green roofs account for 4%, and the degree of support and preference has nothing to do with gender. In the green roof's maintenance management, teachers who expressed their support for setting green roofs account for 95.1%, and among the students 72.3% expressed supported for setting green roofs. And the reasons for people who do not support or assigned maintenance work, or they think that taking care of the green roof is troublesome. In terms of the object of maintain and manage the green roof, the teacher hopes that the green roof can be involved in the curriculum, and they also hope to hire a professional to do the maintenance and management. And the students hope to take turns in class to do the maintenance and management, and they also hope the green roof can be involved in the curriculum.

D. Suggestions on Execution and Design for School Setting Green Roof

The result of collecting the case of schools setting green

roofs show that most of the green roofs are converted from existing buildings' layer roofs and the position of green roofs are not on the same floor with school classrooms, which makes the green roof lack accessibility and visibility. This study investigated the use of space and plane planning and design techniques of Wang Xi Elementary School, and made the green space extend from the terrace to each floor retreat, so that the green roof will not only be set in the top floor of building but also on other floors, which makes the green roof more friendly to teachers and students. The design in this case is the key to the green roof's success, which provides a reference for future planning and designing green roofs.

Surveys show that teachers mostly strongly support green roofs. Teachers who disagree are mainly concerned with the responsibility of maintenance management. Most supporters hope to involve the green roof in the curriculum and hire a professional to do the maintenance and management. Obviously if the maintenance management of the green roof is become a personal burden, the willingness to support will be reduced. As students who support the green roof account for around 70%, the existing green roof is involved in the curriculum of Chong De Elementary School. The degree of cognitive and preference on green roof of Chong De Elementary School is higher than that of Wang Xi Elementary School. But there are still a few students who have no idea accounting for 20% in Chong De Elementary School. It means that there is still room to enhance the degree of cognitive and preference on green roof of students.

Involve the green roof's maintenance management in the curriculum and activate teaching materials, such as adding planting, biological and natural, green landscaping and art, the environment and health education, and other related courses. Let the teacher lead students to get involved in setting green roof, planting activities, propaganda of benefits, and in-depth basic education of the sustainable, ecological environment and other issues. If the students have cognition and affirmation on green roofs, it will be easier to set up the green roof on other types of home and office buildings, and they will become popular in the future.

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