Building and Construction Authority

Ministry of Education
SINGAPORE

TAMPINES SECONDARY SCHOOL

Pilot Project for Sustainable School Campuses

Best-in-Class Super Low Energy Building Series | Institutional Buildings (Existing Building)

Contents

Foreword

In 2021, the Singapore Green Building Masterplan (SGBMP), co-created with the Built Environment (BE) stakeholders and the community, was launched to work towards Singapore's long-term decarbonisation goals.

Since 2016, we have worked with MOE, involving both local researchers and industry experts, to research ways to transform existing schools into sustainable campuses with high energy efficiency and renewable energy adoption. In 2018, Tampines Secondary School (TPSS) was selected as a pilot testbed.

The project team had worked within the constraints of an existing building to maximise the use of naturally ventilated spaces, where practical, to reduce the overall energy consumption.

Together with the use of natural ventilation and other innovative solutions, I am glad to share that TPSS became the first school in Singapore to generate surplus energy in 2021, while enhancing indoor thermal comfort for a conducive teaching and learning environment. This also created opportunities to engage students on sustainability design, practices and technologies.

We hope this research study paves the way to not just shape our schools to be sustainable, but more importantly, impart awareness and knowledge to our future generations in the fight to mitigate the effects of climate change.

Mr Kelvin Wong
CEO
Building and Construction Authority

Foreword

MOE is committed to supporting the Singapore Green Plan 2030 (SGP30), a whole-of-nation movement to advance Singapore's national agenda on sustainable development. Under MOE's Eco-Stewardship Programme (ESP) which is the next bound in our ongoing efforts, schools are guided to adopt an integrative, whole-school approach towards environmental education through the 4Cs – **Curriculum, Campus, Culture, Community**.

Under **Campus**, MOE worked with BCA to trial various sustainability solutions at Tampines Secondary School. Our aim was to identify effective and feasible ways to advance environmental sustainability in campus infrastructure while enhancing the learning environment. The successful trials of the various solutions not only improved the building performance and user experiences in Tampines Secondary School, but also provided a showcase of eco-friendly solutions and learning environments for other school campuses.

The trials at Tampines Secondary School also allowed our students to directly experience how solutions to mitigate the effects of climate change can arise from critical, inventive and adaptive thinking, which are the key 21st Century Competencies we aim to nurture in our students. This authentic learning experience will help our students that we can make a positive difference in sustainability. Our hope is that it will inspire them to contribute as eco stewards and to seek solutions for a sustainable Singapore in the future.

MOE will continue to green our schools and testbed new innovations, so that our school buildings can be more sustainable, and our school campuses can continue to be learning laboratories for our students to see sustainability in practice. The positive outcomes from the trials at Tampines Secondary School gives us confidence that when we approach sustainability challenges holistically, innovate solutions, deploy them adaptively to the local context, and involve our next generation in the process, we can achieve our SGP30 goals together.

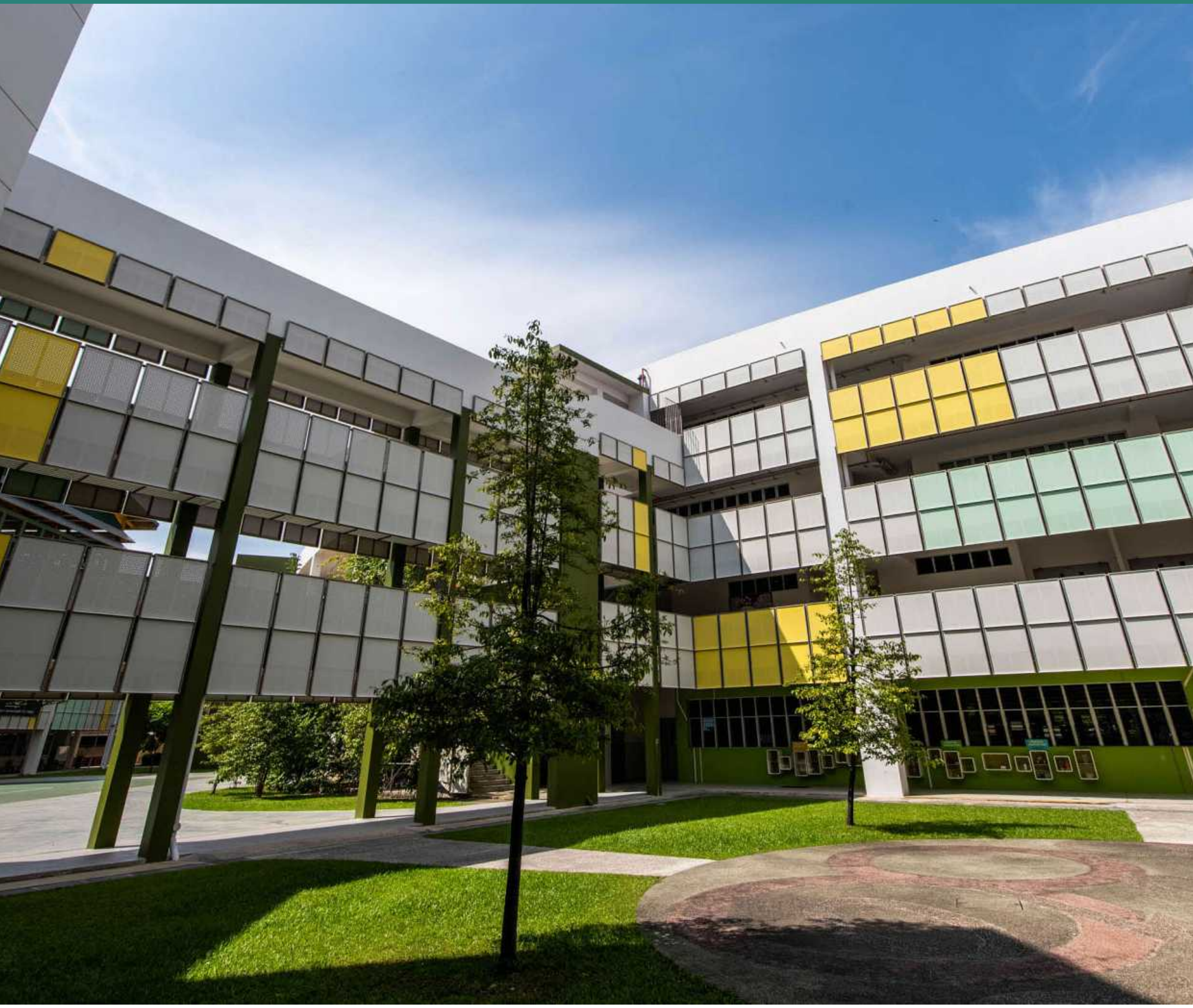
Mr James Wong
Deputy Secretary (Services)
Ministry of Education

Introduction

Even as Singapore's climate grows increasingly warmer, the importance of creating a conducive learning environment for Singapore's future generations has become an even more prescient task.

With a significant number of schools already constructed, BCA worked with MOE to explore how to improve thermal comfort and energy efficiency within the constraints of an existing building.

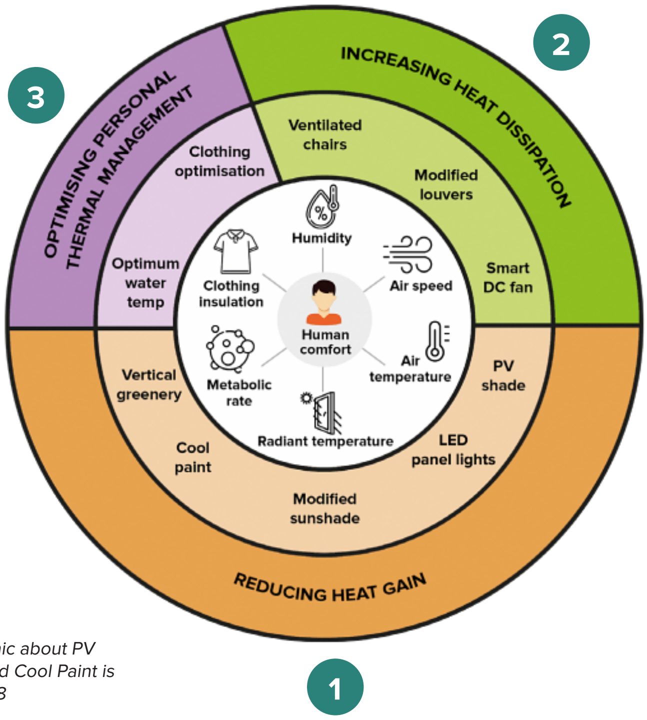
Tampines Secondary School (TPSS) was chosen as a testbed site for this exploration. Ten innovative solutions designed to increase thermal comfort and/or decrease energy use were trialed.

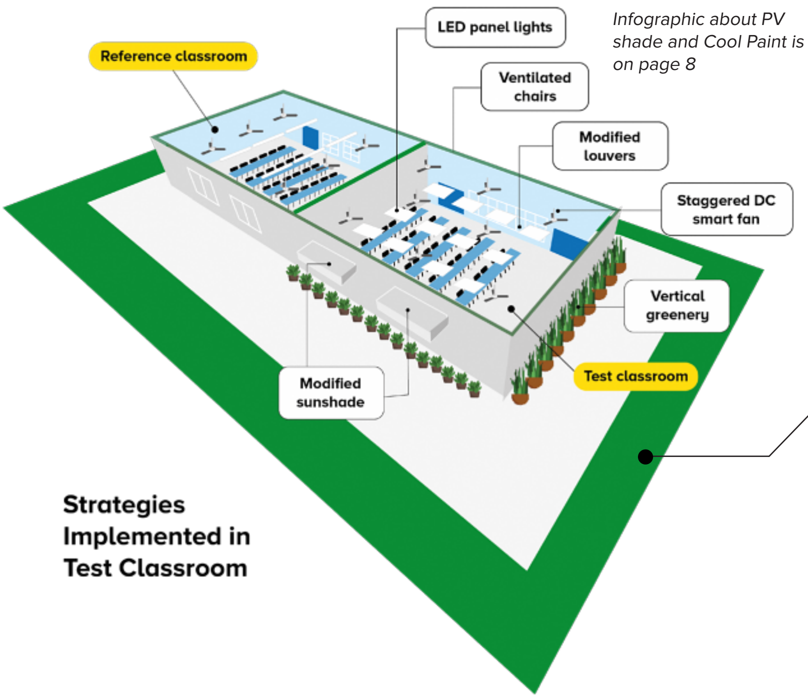


Methodology and Approach

In April 2018, testing was conducted using two adjacent classrooms in TPSS. The Reference classroom was left unchanged, while the Test classroom was implemented with the proposed solutions. The technologies were installed and monitored over eight weeks. On-site measurements and a remote dashboard were used to constantly monitor thermal comfort.

Overall strategies of thermal management in NV classrooms and proposed solutions





Infographic about PV shade and Cool Paint is on page 8

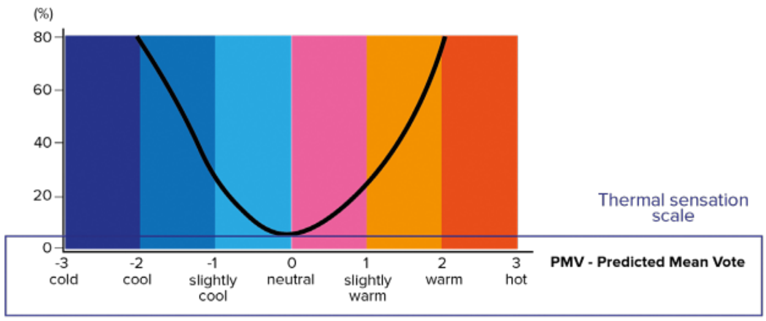
Strategies Implemented in Test Classroom

This pilot test-bedding is the first attempt in Singapore to install and test bed multiple innovations to improve thermal comfort in classrooms. The testing includes technologies that cover various aspects of thermal comfort, making it the most comprehensive testing for classroom thermal comfort in tropics.

How do we measure thermal comfort?

A commonly adopted metric for measuring indoor thermal comfort is Predicted Mean Vote (PMV), which predicts the mean value of subjective ratings of thermal sensation in the giving environment. The thermal comfort is rated on a 7-level comfort scale ranging from cold (-3) to hot (+3). There are six primary factors influencing the thermal comfort and PMV, namely radiant temperature, air temperature, relative humidity, air speed, clothing factor, and metabolic rate.

PPD - Predicted Percentage of Dissatisfied



Reducing Heat Gain

Cool Paint

Technology

For most naturally ventilated classrooms, the greatest source of heat gain is through the roof and envelope. Efficiently managing heat gain in naturally ventilated classrooms is crucial for ensuring optimal thermal comfort. As the primary source of heat gain is through the roof and envelope, addressing this at the source can significantly enhance the learning environment.

Cool paint works by reflecting incoming solar radiation away from the surface it is painted on. This means more heat is reflected away, instead of being absorbed, decreasing surface heat gain.

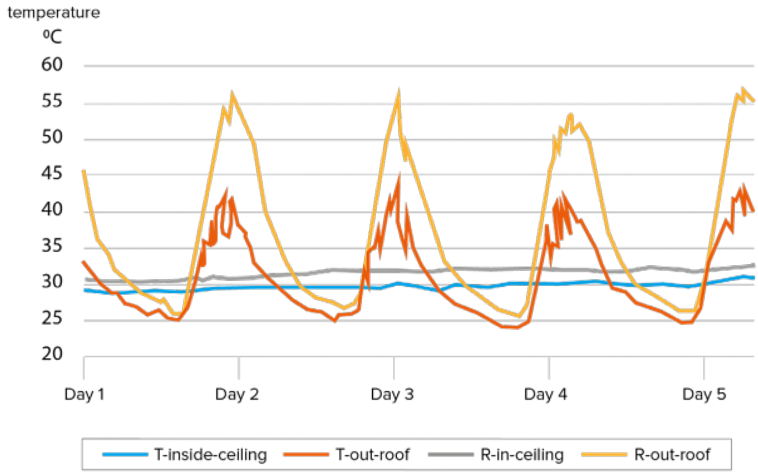
For this test, the roof seal cool paint was applied to the roof, north and east-facing facades of the Test classroom.

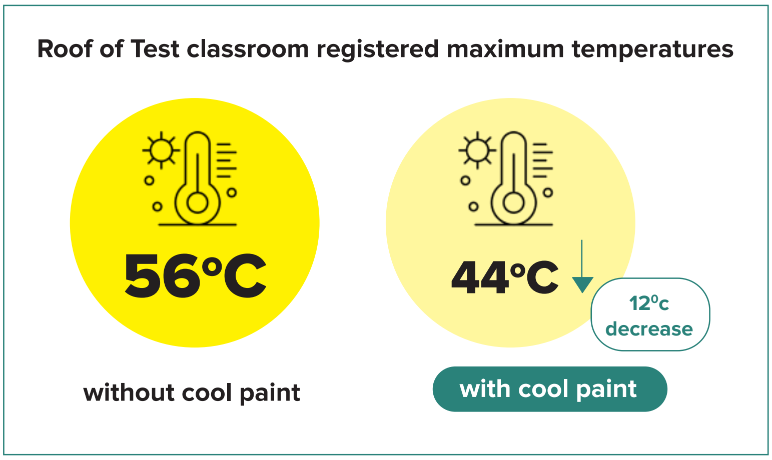
Findings

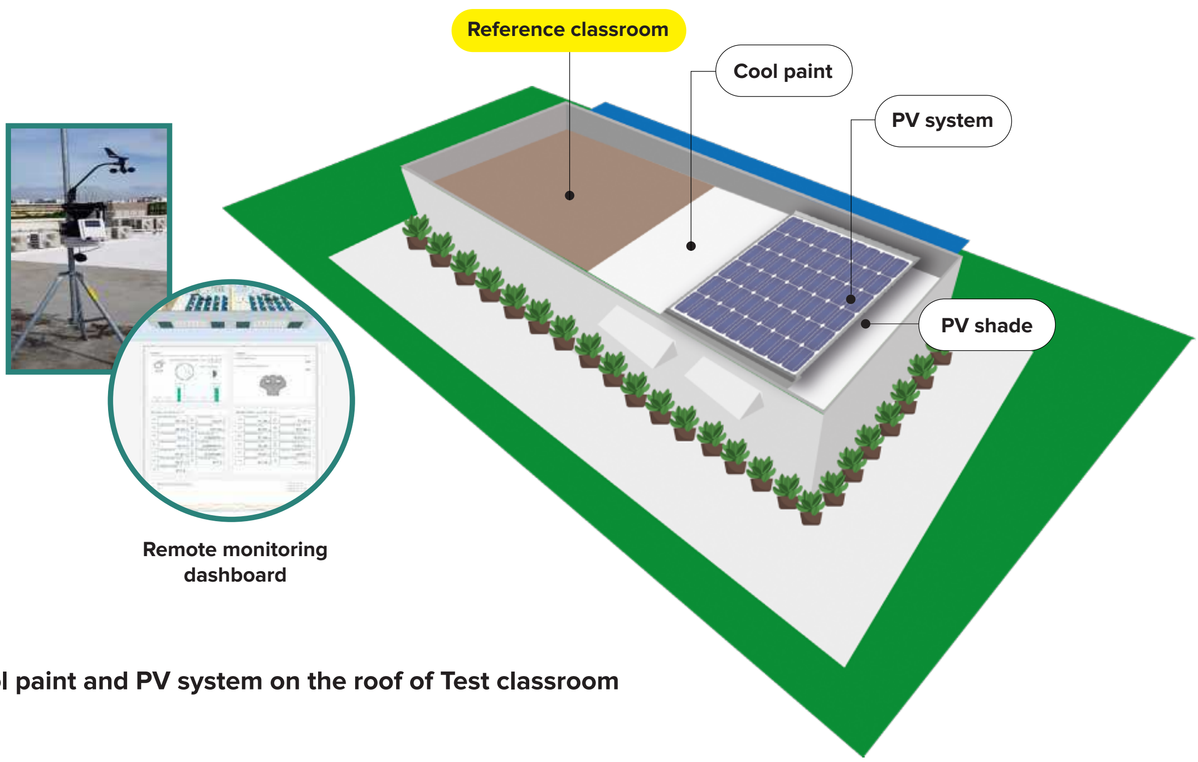
Applying the cool paint to the roof of the test classroom caused a huge drop in external surface temperatures. Without treatment, the Reference classroom registered maximum temperatures of 56ºC, whereas the Test classroom registered a surface temperatures of 44ºC, a decrease of 12ºC.

Keeping all other variables constant, ceiling temperatures were likewise cooler on the Test classroom, registering an average temperature difference of 1.8ºC, fluctuating between 1.5ºC and 2.2ºC.

Roof & ceiling comparison between Test and Reference classrooms







Cool paint and PV system on the roof of Test classroom

Vertical Greenery

Enhancing Greenery

Positioning greenery on the facades of a building can help to reduce heat gain from surroundings. This is due to the cooling from the plants' evapotranspiration. Apart from providing shade and improving the microclimate, plants also add to the aesthetic appeal of the building, and can improve occupants' psychological health.

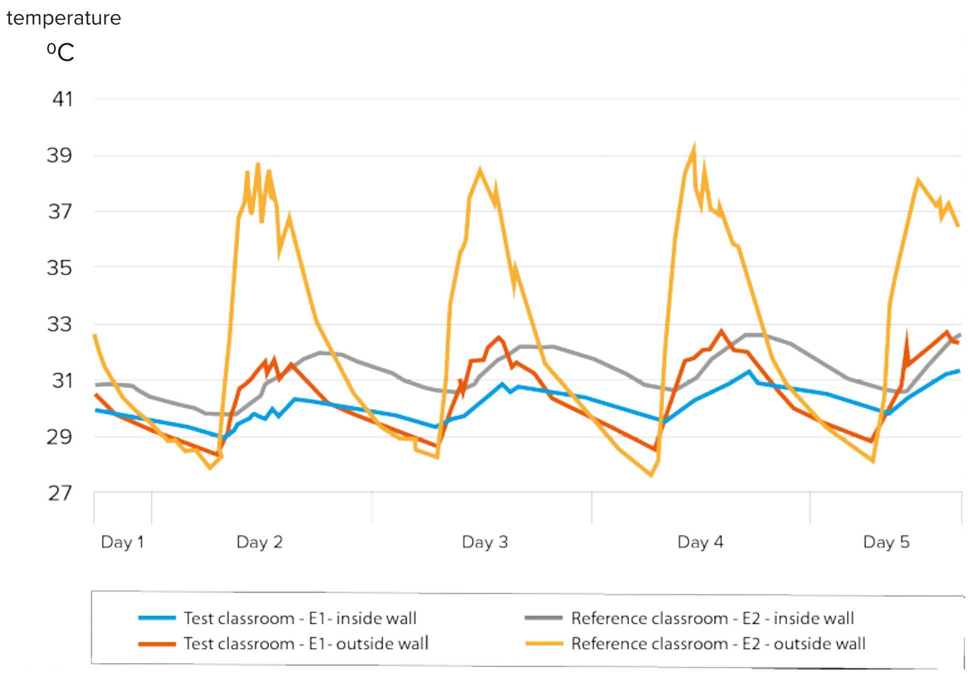
For this test, greenery was placed on the North and East facades of the Test classroom.

Findings

This change led to some improvements for the Test classroom, where the maximum temperature for the outer façade was 6°C lower, and the indoor wall temperature was 1°C lower on average, compared to the Reference classroom.

Positioning greenery

Indoor and outdoor wall surface temperature difference between both classrooms



Sunshade

Technology

Installing sunshades over glazed surfaces has been known to be effective at reducing heat gain inside a building. In recent years, research in Singapore has demonstrated up to an 18.8% decrease in energy consumption for cooling when a sunshade was installed. As such, this was considered a promising technology to be tested on this site, to improve thermal comfort for TPSS' occupants.

At TPSS, rain diverter devices had already been installed over most of the windows to prevent rain from entering classrooms. However, these devices do a poor job of blocking incoming sunlight. To remedy this, the rain diverter across the Test classroom was modified into a perforated panel, preventing sunlight from entering the room. Incoming sunlight tends to cause heat buildup on the floor. This acted as a sunshade for the duration of the test.

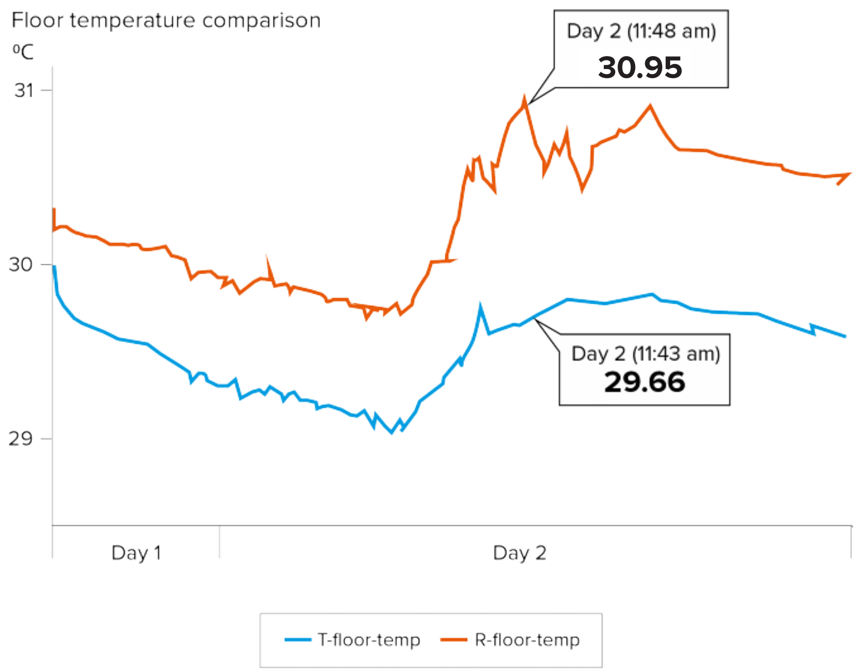
Findings

Comparing the Test to Reference classroom, the sunshades led to a 1.2ºC drop in floor temperature, leading to cooler interiors and a more conducive learning environment for students.

Reference classroom with no sunshade

Test classroom with sunshade

Comparison of floor temperature between Test and Reference classrooms

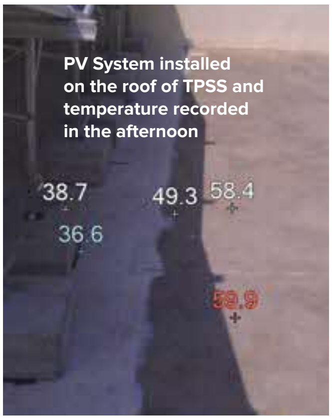


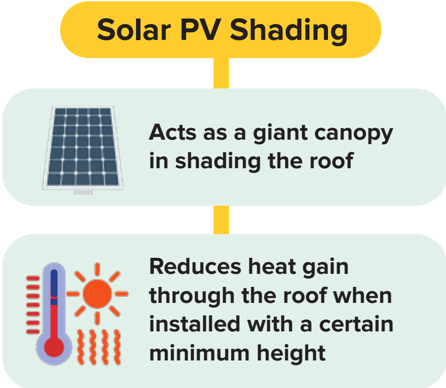
PV shade

Technology

Another measure tested was installing an array of solar photovoltaic panels on the roof of the building at a height of 1m, shading the roof from the sun and decreasing indoor temperatures while increasing energy generation of the building.

Given the significant amount of solar insolation, MOE is optimising feasible roof areas in schools for solar deployment.

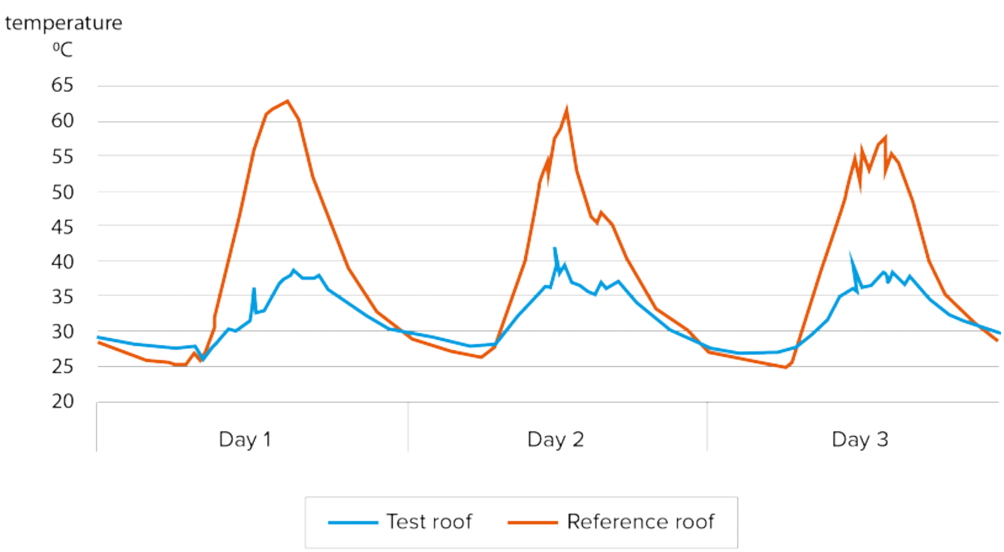




Findings

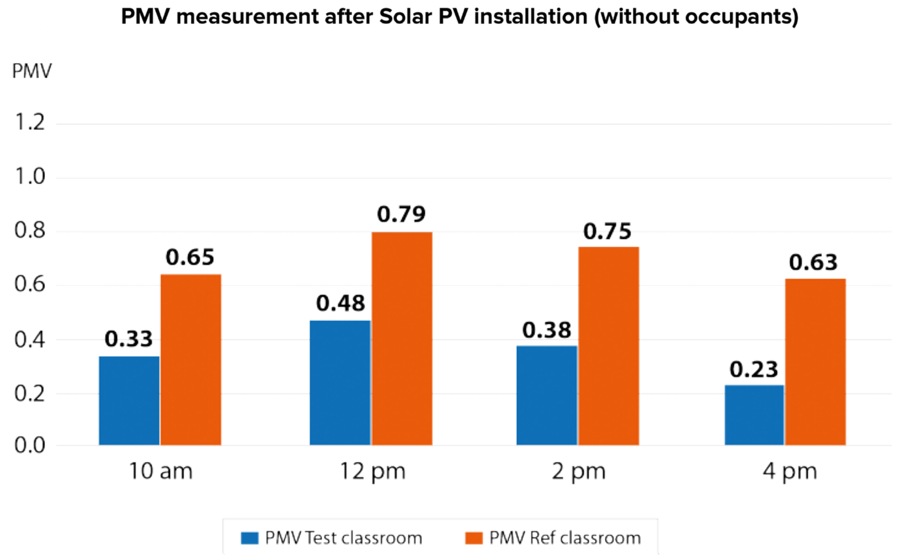
An array of solar panels was installed to cover the roof of the Test classroom, elevated with a gap of one meter from the surface of the roof. On a hot afternoon, the Reference classroom's roof temperatures would often exceed 60°C. However, the Test classroom's roof would generally remain under 40°C, proving the photovoltaic system's effectiveness in keeping the building roof cool.

Roof temperature difference between Test and Reference classroom



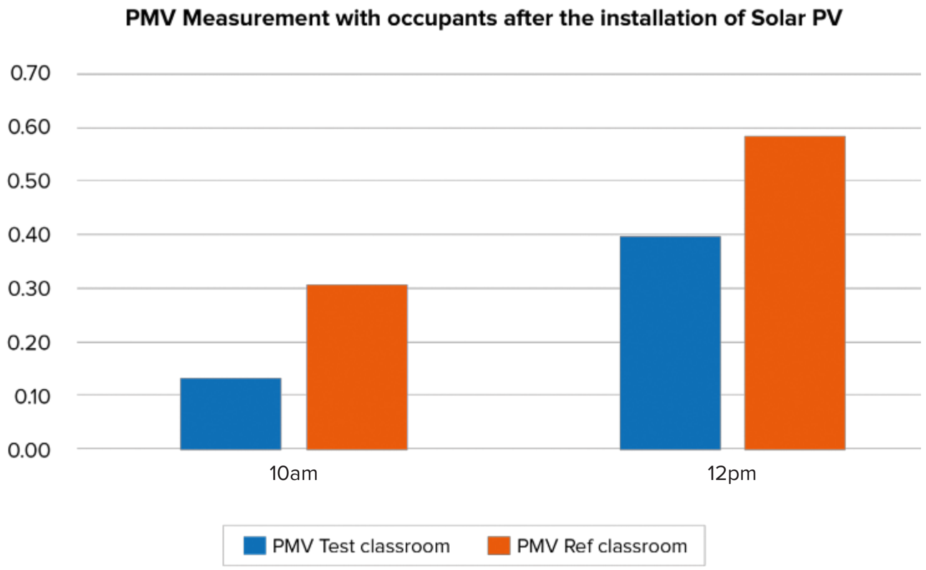
Overall Thermal Comfort

The averaged PMV value (average outdoor temperature of 32°C) has been further reduced after the installation of Solar PV. It is observed that the averaged PMV value of Test classroom is 0.35, while the averaged PMV value of Reference classroom is 0.7. This proves that it is possible to achieve 50% improvement in the PMV (without occupants) with Solar PV shading innovation.



As the room temperature is directly proportional to the PMV Value measurement, occupants such as students and teachers inside the classroom will cause the room temperature to increase due to the heat dissipated from their bodies, resulting in an increase in PMV Value.

The installation of the Solar PV system helps to reduce the heat gain through the roof and there is a significant improvement of 32% in the PMV value even with occupants in the classroom.

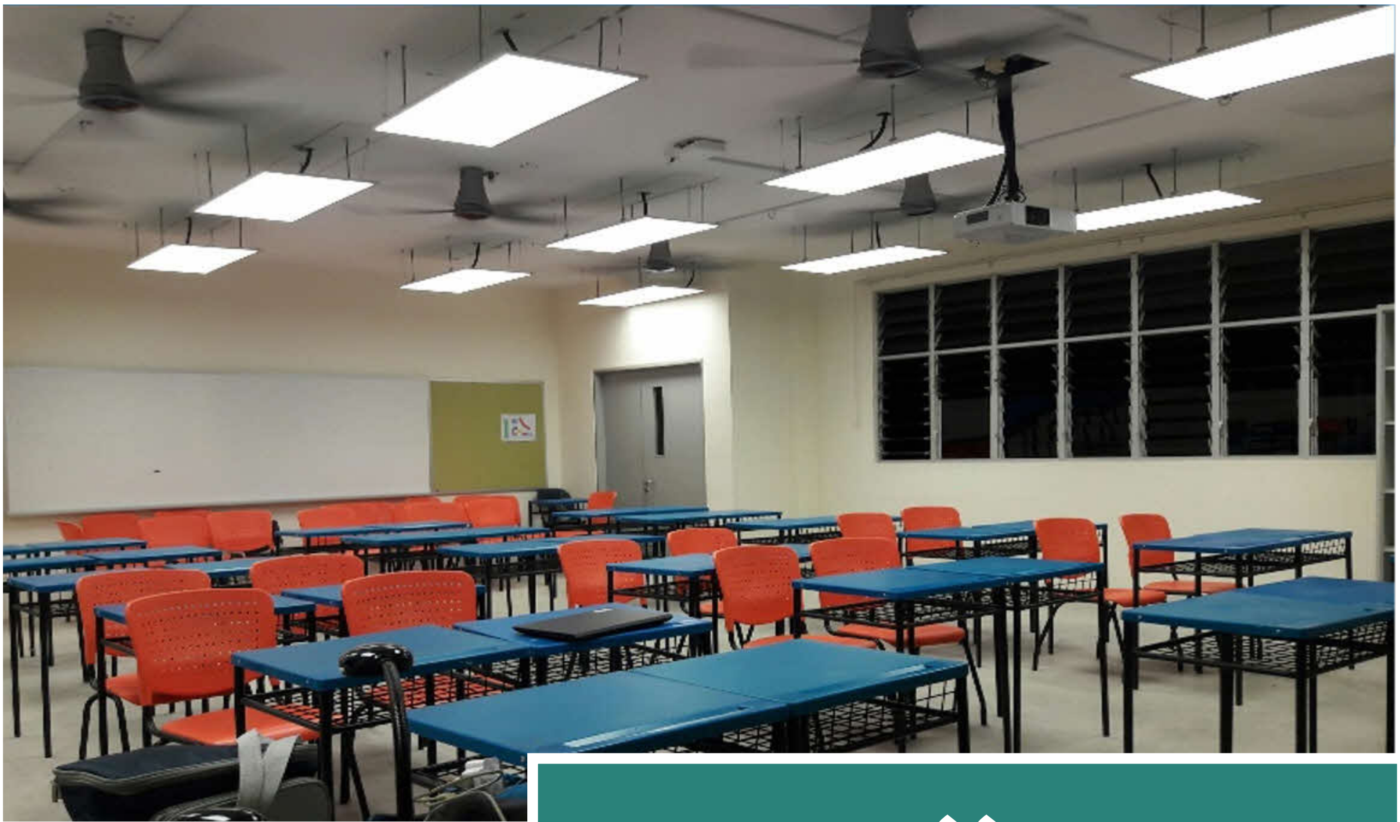


LED lights

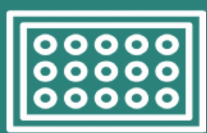
Technology

In the classroom, T8 fluorescent tube lights have been replaced with eco-friendly and energy-efficient LED panel lights that are dimmable with daylight dimming, have a color temperature of 4000K, and belong to the RG 0 group. The RG 0 group classification ensures that the lights are safe for use, emitting no blue light hazard and posing no risk to the eyes. With an L70 lifespan of over 50,000 hours, these LED panel lights are a reliable and long-lasting lighting solution that promotes a conducive learning environment in the classroom.

They offer high-quality illumination, long lifespan, and are safe for use. These lights are available in a 4000K color temperature, which is ideal for schools as it promotes a productive learning environment. They are also batch tested at TÜV SÜD PSB - Singapore, so as to ensure enhanced safety.



LED panel light (in Test classroom)



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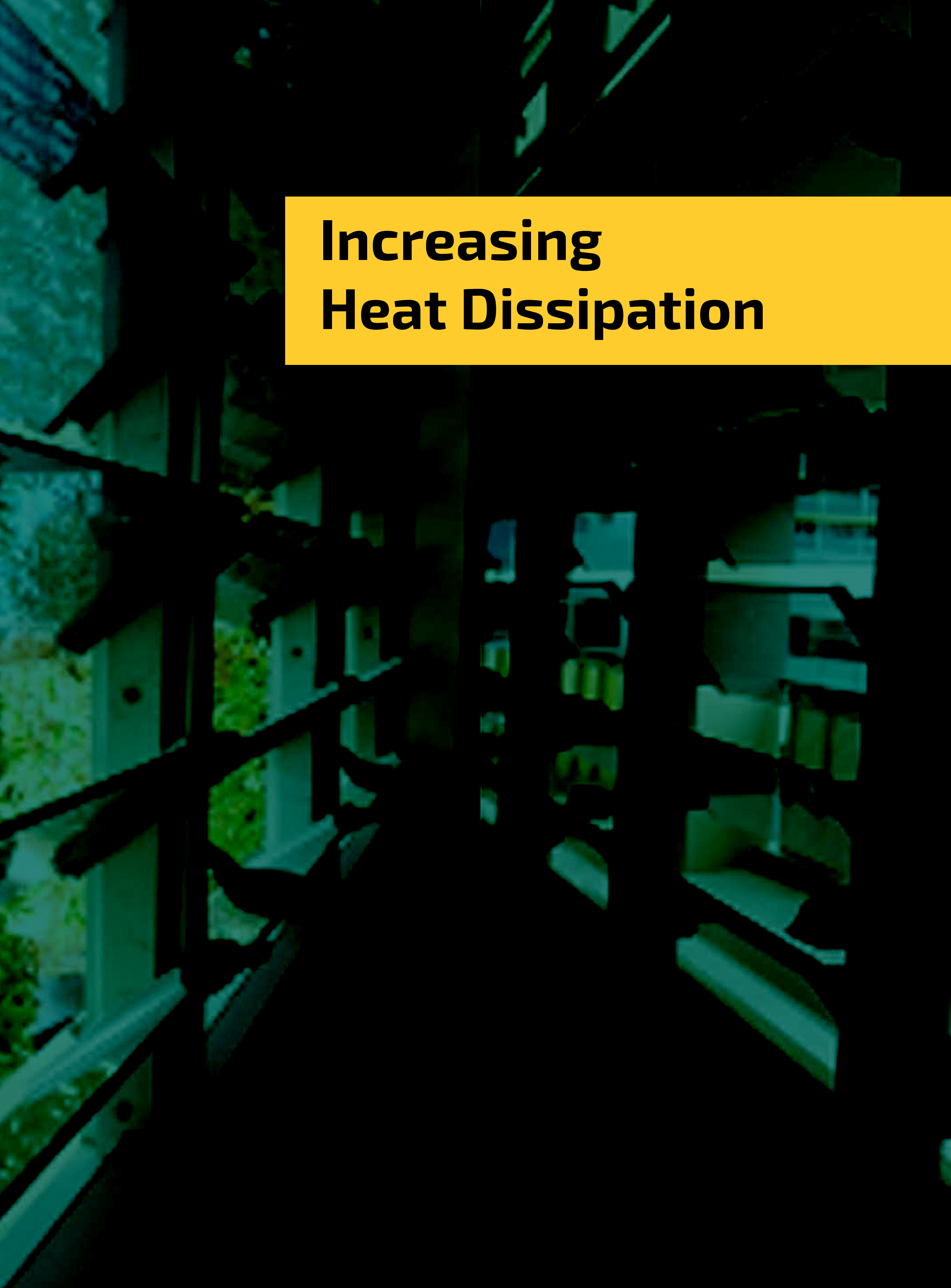


Increasing Heat Dissipation

Optimised louver positioning

Technology

Louvred windows are a standard in every classroom. Though the top section is fixed, the angle of the middle and lower sections can be changed. Under normal circumstances, the middle and lower sections are pointing downwards at a 45 degree angle. This was maintained in the Reference classroom.

However, in the Test classroom, this angle was changed to an upwards-facing tilt, inclined at 135 degrees. This was aimed at accelerating the dissipation of hot air, which naturally rises.

Findings

Comparing the two classrooms, this simple, free change to the louver setup in the test classroom resulted in a significant 82.3% increase in outflow rate of hot air. This greatly improves heat dissipation in classrooms, enhancing thermal comfort for students and teachers.

Louvers inclined at 45° to the horizontal (left), **louvers inclined at 135° to the horizontal** (right).

> **Free change to the louver setup in the Test classroom resulted in a significant 82.3% increase in outflow rate of hot air.**

Smart DC fans

Technology

The majority of naturally ventilated classrooms in Singapore rely on fans to circulate air and keep students cool. However, little attention has been given to optimizing the placement and positioning of fans to maximize cooling efficiency. Additionally, the noise generated by fans can be distracting and disrupt students' learning, while the high energy consumption of traditional fans leaves room for improvement. Initial testing of a Reference classroom revealed poor airflow near the front of the room and highly uneven airflow throughout.

To address these issues, eight Smart Direct Current (DC) fans were installed. These fans consume less energy and automatically adjust their speed based on the indoor air temperature, resulting in additional energy savings without compromising comfort. The optimized placement of these fans has significantly improved airflow and created a more conducive learning environment students.

The results obtained, based on 30 point measurements in a 90 sqm room, has shown that the minimum air velocity improved by 0.4m/s, At the same time, there were noise reduction of 2 dBA and energy savings of 24% compared to the current fans.

> 24% — **Energy savings**

0.4m/s — **Minimum air velocity improved**

2dBA — **Noise level reduced**

Self-adjustable speed based on temperature

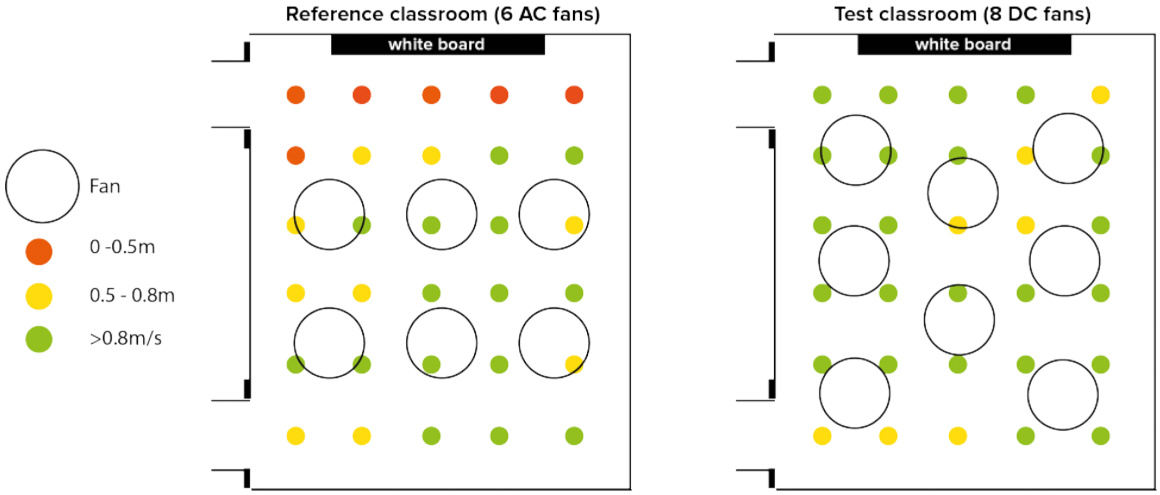
Findings

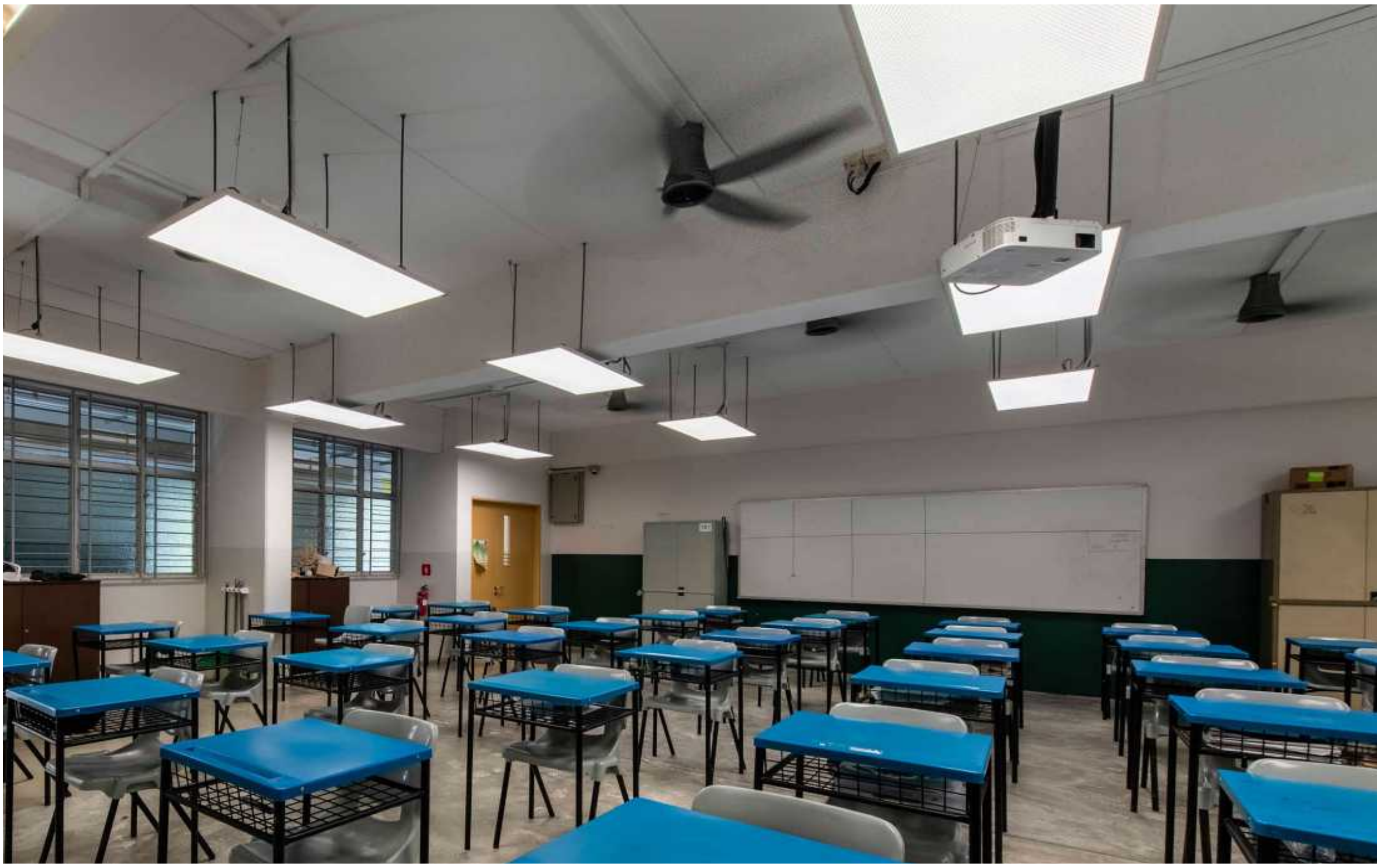
To optimise fan placement, the existing six alternating current (AC) fans, positioned in a two-by-three grid, were first removed. In its place, eight smart DC motor fans were installed in a staggered fashion, with the hopes of increasing airflow and cooling uniformity, while also reducing noise.

Studying the Test classroom revealed greatly increased airflow velocities at the front of the classroom, and also a greater uniformity of air distribution.

Average noise levels in the classroom were also observed to have decreased from 66.3 dBA to 64.5 dBA, despite the higher number of fans.

Air velocity distribution





Ventilated chairs for test classroom

Ventilated Chairs

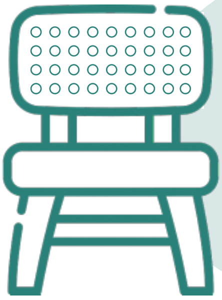
Technology

In general, chairs used in schools offer a solid-backed design. This causes heat to build up on the student's back over time, reducing thermal comfort.

Ventilated chairs simply introduce many small holes in the back of the chair, allowing for heat to dissipate more readily from the student. Such a design is well-suited for the tropics, where the demand for thermal comfort is very high.

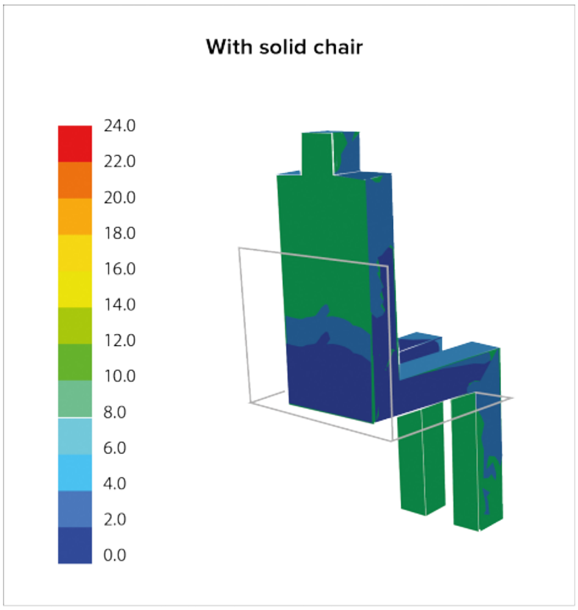
Findings

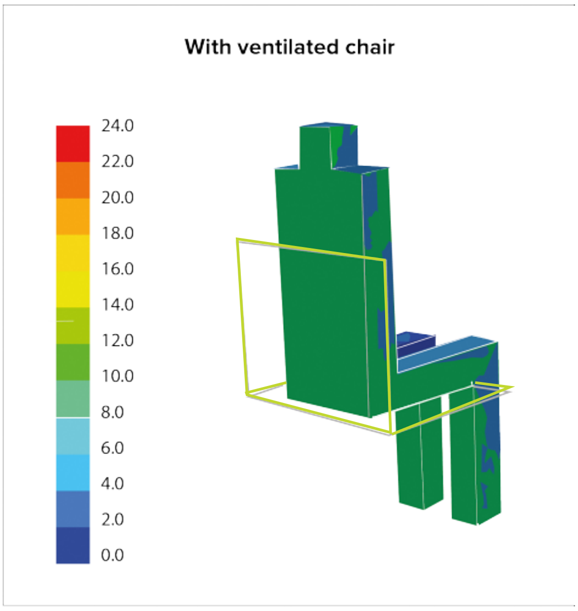
Replacing a solid-backed chair with a ventilated design in the test classroom resulted in a 35.7% increase in surface heat transfer coefficient. This reflects the drastic benefits of improved ventilation, allowing moisture to be wicked from the student's body more quickly, keeping students comfortable.



Replacing a solid-backed chair with a ventilated design in the test classroom resulted in a 35.7% increase in surface heat transfer coefficient.

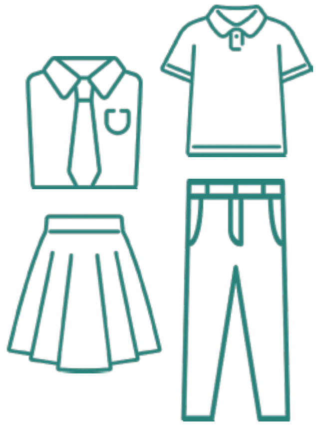
Contour plot of surface heat transfer coefficient, W/m² °C





Optimising Personal Thermal Management

Clothing Optimisation



Technology

Keeping cool in the tropics can be greatly aided by the type of clothing chosen, especially for school uniforms adopted by hundreds of students. The right choice of uniform and fabrics can greatly improve thermal comfort for each student, and can also decrease energy required for cooling.

Findings

After discussions with TUV-SUD-PSB, a set of guidelines for optimal school uniform thermal performance was developed. Current and future school uniform designs may be tested against these guidelines, to determine how far they deviate from the norm.

Various requirements recommended by TUV-SUD-PSB

Description	Test standard	Recommended requirement
Wicking rate (mm/sec)	AATCC 197	For sportswear: at least 75mm at 10 mins For summer season's garment: at least 50mm at 30 mins
Drying rate	JIIS L 1906	<2h
Water vapour transmission rate	ASTM E96, BW method	>300 $^{g/m2}$ = 24 hours
Water absorbency	AATCC 79	<5s
Thermal absorptivity ($Ws^{1/2}/^{m2}K$)	ASTM D1518	0.6 CLO value -0.2 to null deviation

Water Temperature Optimisation

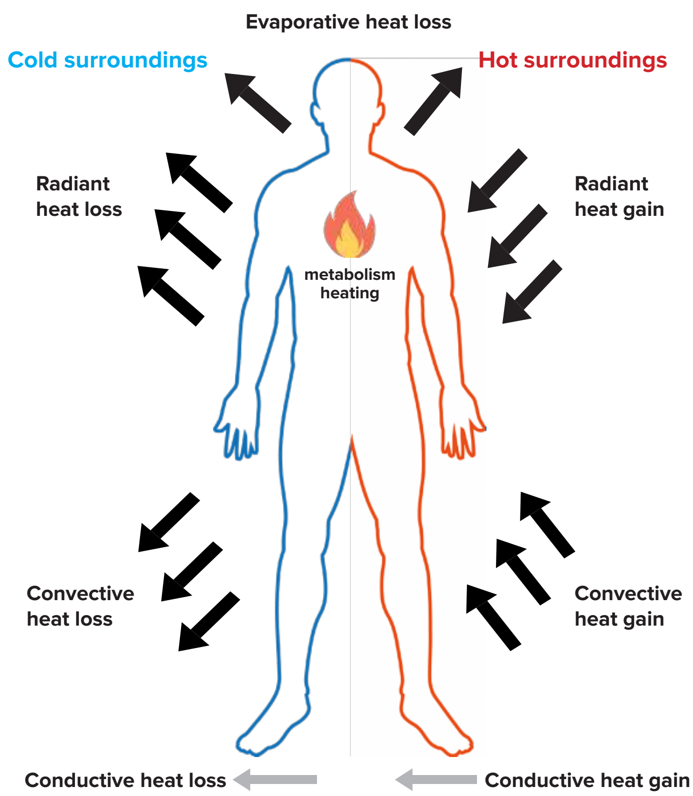
Technology

Research[1] has showns that the optimum water temperature for rehydration is 16ºC, which provides the most optimal metabolic rate for the human body even as external temperatures rise.

Findings

To achieve optimal rehydration for students and teachers, the water coolers have been set to a temperature of 16°C. Timers have also been installed at each cooler, turning them off on weekends and holidays to conserve energy.

This measure is projected to create an annual energy saving of 10.6 kWh for the 15 water coolers installed in TPSS.



[1]Hosseinlou. A, Khamnei. S, Zamanlu. M. (2013). "The effect of water temperature and voluntary drinking on the post rehydration sweating". Int J Clin Exp Med 2013;6(8), pp.683-687

Thermal Comfort Survey

Thermal comfort & thermal environment study

- **Date, time and venue:** 30 Oct to 1 Nov 2018, between 8am to 1pm at TPSS
- **Participants:** 54 students (15-16 years old) and 2 teachers (40-50 years old)
- **Student gender:** 23 are males while the remaining 31 are females
- **Activities of all respondents:** seating, reading and teaching
- **Students' attire:** Male students wore a uniform of white short sleeve shirt and dark green pants and female students wore white short sleeve shirt with dark green skirt. Some wore the PE T-shirt while some others wore the PE T-shirt underneath their uniform.

The air temperatures ranged from 29.9 to 30.9°C and the relative humidity was 62-78 per cent. The measurement was carried out on a hot day. The air temperature varied from 28.5 to 30.1°C on the second and third day.

Reference classroom

Test classroom

Survey Conclusion

The survey provided a substantial contribution that would enable further progress to be made with regard to the issue of thermal comfort in hot and humid climates. The analyses show that:

- the indoor thermal environments of the Reference classroom were higher than Test classroom
- thermal comfort of classrooms can be reached when natural and mechanical ventilation are properly positioned and improved, which was shown by the innovative designs in the Test classroom

The summarized key conclusion are as follows:

95%
of the respondents in the Test classroom felt more comfortable

100%
of teachers felt that the Test classroom enables them to teach better and students were able to concentrate better as compared to Reference classroom

63%
of the students in Test classroom agreed that they could hear their teacher more clearly

55%
of the students agreed that they could concentrate better in the Test classroom as compared to Reference classroom due to the improved thermal comfort

From the results, we can conclude that the Test classroom provides a much more conducive learning and teaching environment for students and teachers.

Overall Findings

Overall Findings

To understand the thermal comfort experienced by students, the predicted mean vote (PMV) model was used. A lower PMV score demonstrates better thermal comfort.

After implementing the technologies, the average PMV of the test classrooms demonstrated a 50% improvement without occupants, and 32% improvement with occupants. Such a drastic improvement has eliminated the need for air conditioning in most scenarios.

TECHNOLOGY	TANGIBLE BENEFITS	INTANGIBLE BENEFITS
LED Panel Lights	50% energy saving	• Safe LED panel lights • Daylight dimming (Enhancing more natural light) • Uniformity >0.7 • Colour Rendering Index CRI > 80
Smart DC fans	24% energy saving	• Improved minimum air velocity to 0.4 m/s • Reduce noise level by 2 dBA even with two additional fans
Cool paint	NA	• Average roof surface reduction of 10ºC • Maximum ceiling surface reduction of 2.2ºC
Vertical Greenery	NA	• Maximum roof surface temperature reduction of 12ºC • Maximum indoor wall surface temperature reduction of 1.7ºC
Sunshade	NA	• Maximum indoor floor surface temperature reduction of 1.3ºC
PV Shade and cool paint	NA	• Maximum roof surface reduction of 27ºC
Ventilated chairs	NA	• Surface heat transfer co-efficient improved by 37%
Optimised water temperature (16ºC) and Timer control	saved 10.6 kWh/annum	• Optimal rehydration for staff and students
Modified Louvers	NA	• Increased heat dissipation up to 82.3%

The minimum air velocity was improved from 0.2m/s in the Reference classroom, to 0.4m/s in the Test classroom. Such a near-twofold improvement has led to a 24% reduction in energy consumption and a 2dBA reduction in noise.

The application of cool paint has resulted in a maximum reduction of 12ºC in the roof surface temperature and 2.2ºC in the indoor ceiling surface temperature.

Altogether the tests have demonstrated the efficacy of all innovations explored. Though some may offer small gains, cumulatively their effects have led to an enhancement in thermal comfort, even under the most unfavourable conditions. This has also been achieved in tandem with a decrease in energy consumption and environmental impact. Such improvements demonstrated are capable enough for the school to achieve good thermal comfort.

Given how such performance gains were realised even when retrofitting an existing school, the innovations proven at TPSS have paved the way for other existing schools to follow suit. Such retrofitting has already proven itself to be cost-efficient and yet highly effective.

Results at TPSS have demonstrated how to enhance thermal comfort without resorting to air conditioning. As such, using air conditioning should be considered as a last resort, rather than the first line of defence, in improving thermal comfort efficiently. Enhancing thermal comfort smartly has potential to lead to greater cost savings in the long run, compared to simply adding another air conditioner.

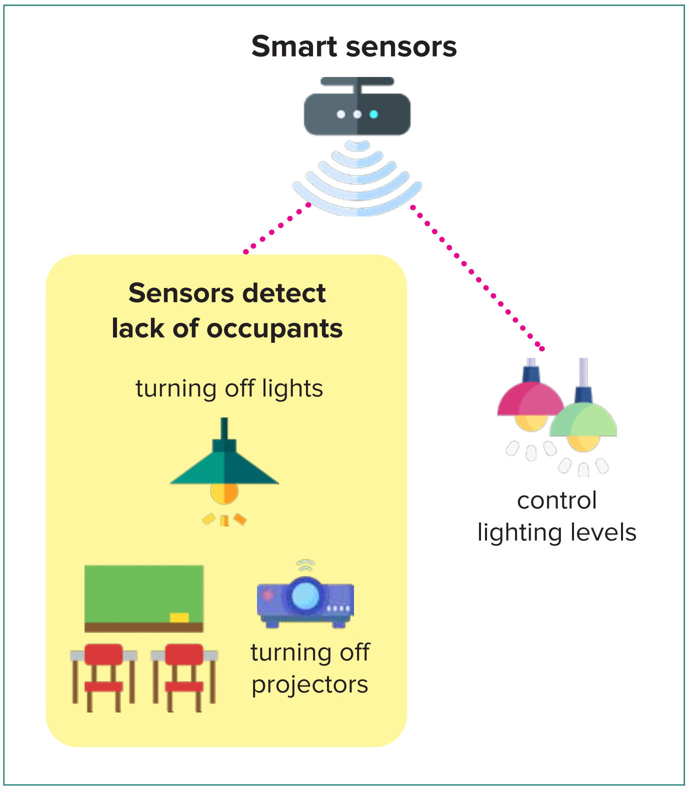
Even as the testing at TPSS has demonstrated excellent results, efforts are underway to push the envelope even further, towards more sustainable and conducive school campuses.

One major plan is to equip school areas (for example, Staff areas, Library and Computer rooms) that have higher traffic or electricity consumption with occupancy, light and temperature sensors. This will generate energy savings, as the lighting brightness and air-conditioning temperature settings can be automated and optimised based on the occupancy level, ambient lighting and temperature. For example, lightings and air-conditioners in these rooms will be switched off automatically, if they are vacant; and cubicles, that are near windows enjoying daylight harvesting, will have dimmer indoor lightings.

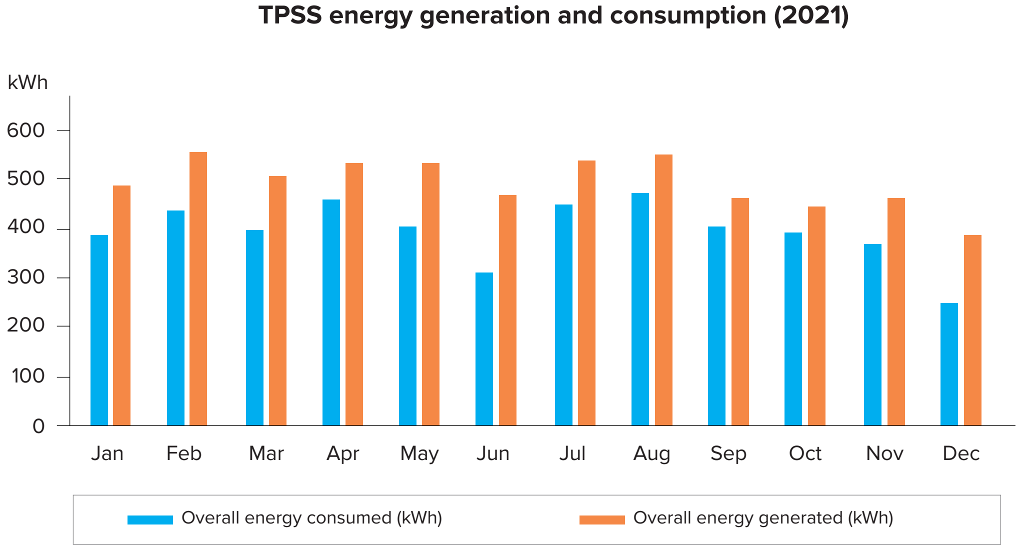
Other schools are likely to follow suit in TPSS' path, learning from their outcomes to arrive at their own sustainable designs.

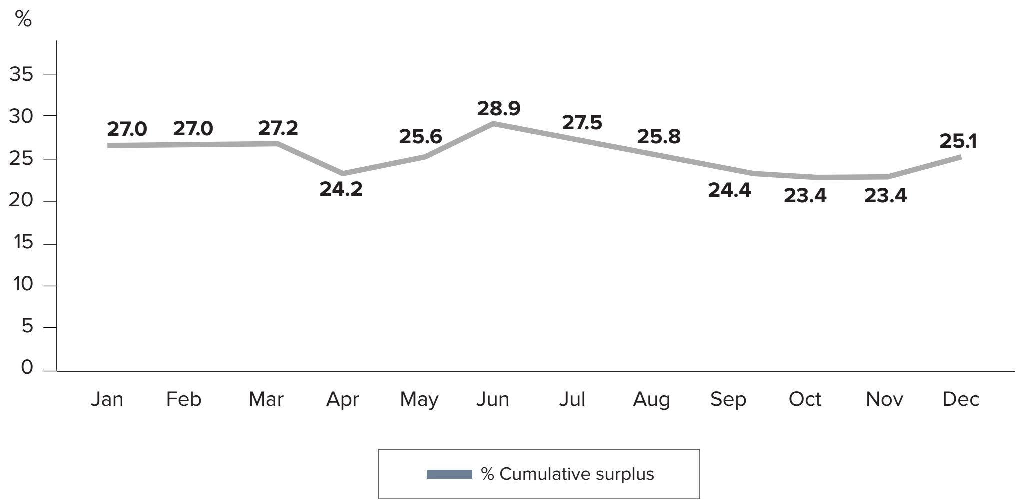
The research and development done at TPSS has provided Singapore with a glimpse into the future of schools. A future where schools can be thermally comfortable without air conditioning.

A future that can be realised, today.



Overall Energy Surplus





Following the implementation of energy-efficient measures throughout TPSS and the installation of solar panels, TPSS achieved a cumulative energy surplus of 25.1% per annum (2021). This means that TPSS was able to generate more energy than it consumed, resulting in a surplus of 25.1% of its total energy needs annually. This achievement is a testament to TPSS's commitment to sustainability and energy efficiency,

Challenges Faced

Challenges Faced

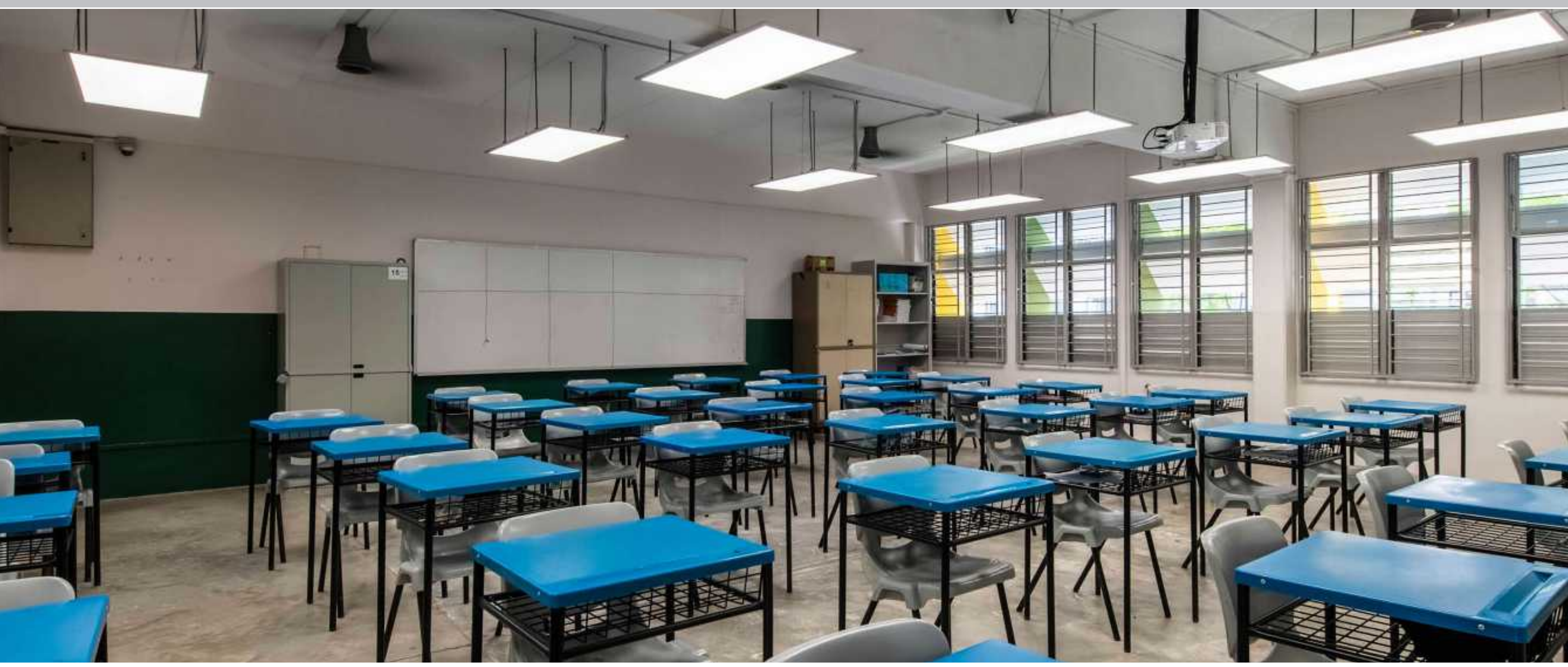
1

One of the challenges faced by Tampines Secondary School was the rooms' configuration. Not all rooms were uniform in their configuration resulting in additional time being taken to determine the right place to mount the fans and lights for optimum outcome. There were also rooms that required additional mounting due to the beams. The science laboratory posed a separate challenge due to the additional pipes on the ceiling. Care was needed in placement of the fans and LED lights to avoid the pipes, at the same time determining the right location to provide maximum comfort to students.

2

The quality of the LED lights drivers was also of concern. It was discovered that there were at least one or two drivers a day that needed to be replaced. The school had to request new LED drivers from LED lights supplier and coordinate with the Term Contractor (TC) the appropriate date and time for the replacement in order to minimise disruption.

Nevertheless, through close collaboration between the various stakeholders, we were able to address and resolve these challenges.



Next Steps

Next Steps

MOE will progressively implement sustainable features such as cool paint, energy-efficient LED lights and Direct-Current ceiling fans in more schools. To further reduce schools' electricity demand on the national power grid, we are actively deploying solar panels and other smart facilities management technologies in our schools.

MOE will continue to adopt new technologies and approaches to enhance our school infrastructure so that we can provide a conducive learning environment while supporting our sustainability efforts under the Singapore Green Plan 2030.





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TAMPINES SECONDARY SCHOOL