Cool and Comfortable in the UNESCO World Heritage in Singapore

The National Orchid Garden is the crown jewel of the Singapore Botanic Gardens, and one of the main attractions with its beautiful and detail-rich displays of orchids. Since 2015 the National Orchid Gardens is a UNESCO heritage site. The current enhancement of the gardens refreshes the visitor experience and increases the displays to 1,500 varieties of orchid species and 3,000 varieties of orchid hybrids. The main areas of the enhancement include the Tropical Montane Orchidetum, Burkill Hall, and the Orchid Cooled Nursery. In April 2021 it officially opened its doors to the public.
Transsolar has been involved in the project since the very first phases of the project to develop climatic concepts for the Cool House but also for the other pavilions and outdoor areas of the garden.

Climate experience and concepts

Creating thermal comfort and perfect special habitat growing conditions for orchids is a demanding task. The proposed concepts are based on advanced human bio-climatic models for thermal comfort, such as UTCI. With these complex models the design process can be informed better, strategies are much richer, and cooling and air conditioning systems can be reduced without compromising thermal comfort and growing conditions.

Tropical Montane Orchidetum

The Tropical Montane Orchidetum will comprise 3 different climatic conditions: The Bromeliad Collection will showcase low-elevation forest conditions (say 28 .. 32°C), The Mist House will showcase mid-elevation forest conditions (say 24.. 28°C) and The Cool House will showcase high-elevation forest conditions (say 20.. 24°C).
With display of species of increasing elevation, a higher level of environmental control is required mimicking the required conditions. Whereas for low- and mid-elevation open structures with refined misting systems are sufficient, for the high-elevation a fully controlled and closed cool house environment is required.

Figure 1 Orchid Park at Botanical Garden Singapore

To create a seamless visitor experience, the transition from the outdoor to the indoor environment and back can be camouflaged given the very specific topographic situation at the National Orchid Garden. The visitor flow is guided from the open garden spaces which are located higher on the hill side to the fully environmentally controlled cool house defining the lowest location in the National Orchid Garden. Natural stratification keeps the layers of cool air at the cool house level. The higher the elevation the lesser control will be required and the more porous the structure will become. The environmental control is facilitated, and doors and air locks can be reduced to a minimum.

The concept is reversing the temperature stratification as found in nature with warm temperatures at lowlands and with elevation decreasing air temperatures.

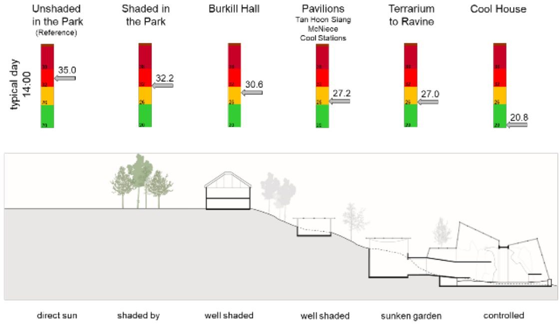

Figure 2 Thermal comfort narrative for visitors

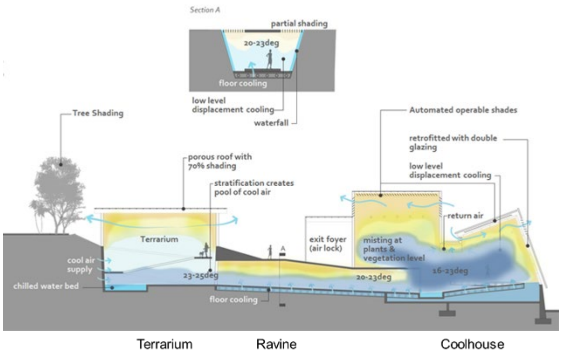

Figure 3 schematic section Orchidetum indicating comfort narrative at competition stage

Cool House concept

Conditioning of a glazed cool house in Singapore´s climate can be energy intensive. Once the cool house is in operation the active systems typically run all year round. Sustainable and environmentally friendly concepts maximize the efficacy of techniques rather than having them focus on optimizing the efficiencies of single applied technologies. The innovative and integral architectural and climate engineering strategies assure energy efficiency in cooling, while balancing optimal conditions of light, temperature and humidity for plant growth and human comfort.

From the horticultural view, maximum light is desirable; for human comfort controlling solar gains is crucial to reduce cooling energy. With the fully glazed envelope high selective glazing with high transmittance in the PAR spectrum but low solar heat gain is key. The glazing features a second low-e layer facing inside to reduce secondary heat load and to deal with the radiant cooling. The optimization of the envelope significantly reduces the required cooling systems and energy demand.

The active cooling of the cool house is achieved by a combination of radiant cooling in all occupied areas and displacement ventilation. The amount of fresh outside air is well balanced to the requirements of plants and visitors. The air tightness of the building and systems is optimized to reduce infiltration.

High pressure localized misting systems have been integrated in the volume of the cool house. The control of the misting system is carefully synchronized with the variable air flow and air humidity requirements to ensure optimal growing conditions as well as optimal climate control.

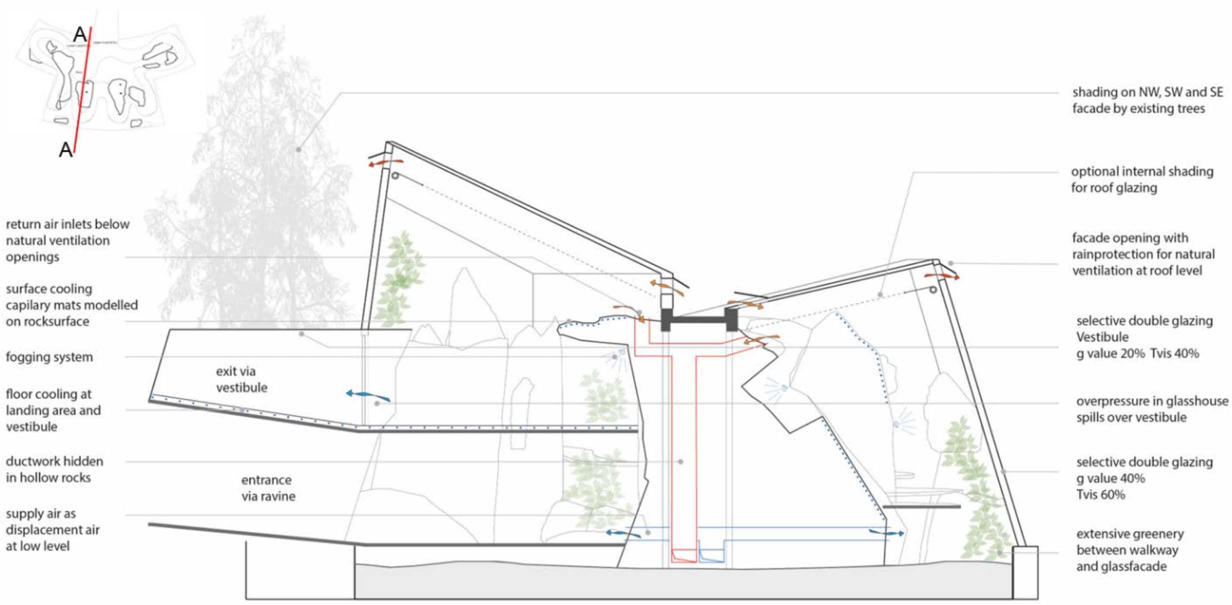

Figure 4 Concept elements of facade, ventilation and conditioning.

A project with all facets of climate engineering

In addition to the wonderful implementation of this outstanding project, the National Orchid Garden required to integrate complex aspects of conditions for plant growth, visitor comfort and operation. Many different tools and methods have been developed and used within the design process. Tasks ranged from onsite measurements to state of the art thermal and daylight simulations, all done to inform the design for the best possible project outcome. The project started with a site visit of the team, where various measurements have been carried out. The measurements were basis for the project simulations as well as design decisions. With these data measurements a digital twin of the existing building has been created and calibrated. Also, these measurements were used to verify, calibrate and further develop our simulation tools. In this project all passive elements or strategies proposed by TS were measured and the performance verified.

Glazing quality

The solar and visual transmission of the existing glazing have been measured to determine the current energy transmission as well as daylight levels within the glasshouse and to evaluate the glazing quality. These data have been used to choose the glazing parameters for the new building with the optimum of reducing solar transmission to reduce cooling effects and receiving sufficient daylight for plant growth.

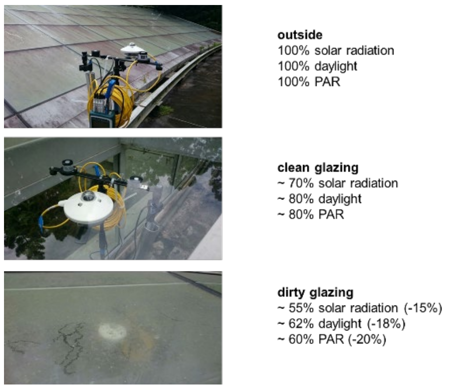

Figure 5 The existing glazing created a significant reduction for the solar radiation. Still, the light conditions were sufficient for the plants.

Shading - Parametric tree modelling

Parametric 3D modelling has been used to create a 3D model of the trees within the park to create a surrounding model for the glasshouse. The model has been developed based on provided measuring data and satellite images and was verified by a so-called sun eye camera. The sun eye camera uses a special fisheye lens to take a 180° wide angle image of the half sphere which can then be used to overly sun path of the location. The model was used to determine shading by trees on the glasshouse, which was considered in all thermal and daylight modelling.

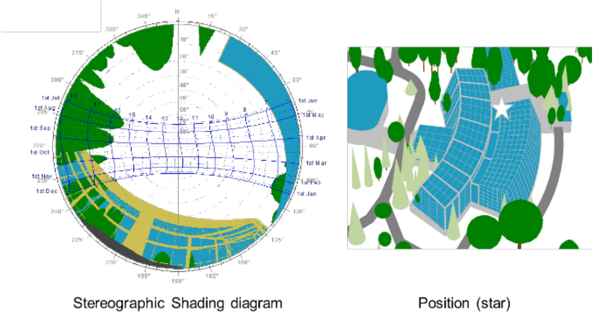

Figure 6 Sun Path diagram to evaluate the shading by the surrounding trees.

Temperature and Humidity Stratification

Furthermore, temperature and humidity measurements within the glasshouse could visualize the temperature stratification inside the building. It was shown that the upper layers of the glasshouse heat up significantly compared to the other zones. With this information, positions of natural ventilation openings as well as exhaust air inlets have been optimized.

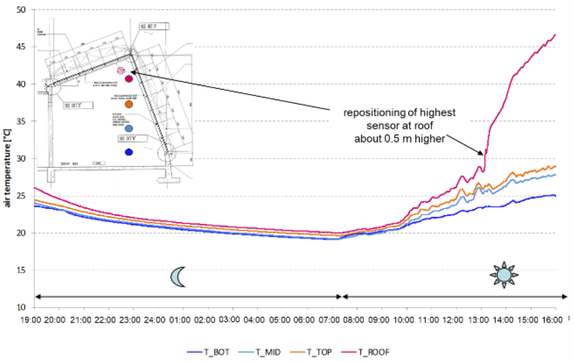

Figure 7 Temperature stratification in Cool House Monday/Tuesday 15/16.02.2106

Comfort improvement by plants

With the help of infrared cameras surface temperatures of e.g., vegetation has been measured. Due to the evapotranspiration of plants, the plants not only provide an evaporative cooling effect but also have a lower leaf surface temperature than other surfaces and so have a big influence on the radiant environment and hence comfort. The images show plants inside and outside the glasshouse and indicate that, even in full sun exposure, plants´ leaves are always cooler compared to other surfaces as e.g. glass or wood.

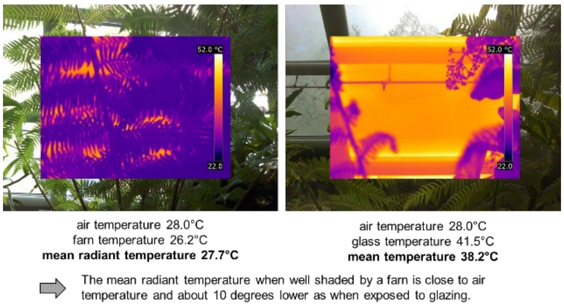

Figure 8 The shading by plants in the Cool House was considered for the comfort concept

Figure 9 The MRT of vegetated surfaces is significantly cooler

View factor evaluation

View factor determination by sun eye camera have been carried out. View factors show how much a person is exposed to a specific surface with a certain radiant temperature, hence they have a big influence in determining indoor and outdoor comfort conditions.

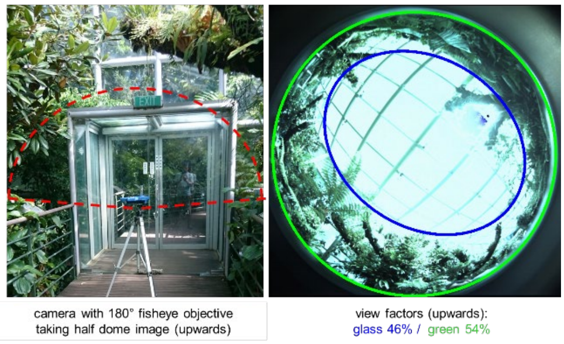

Figure 10 Determination of view factors to glass and green

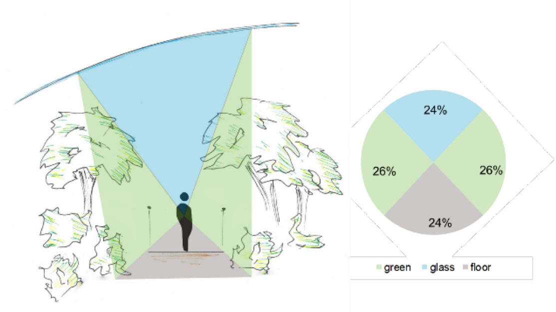

Figure 11 View factors to elements with significantly different mean radiant temperature

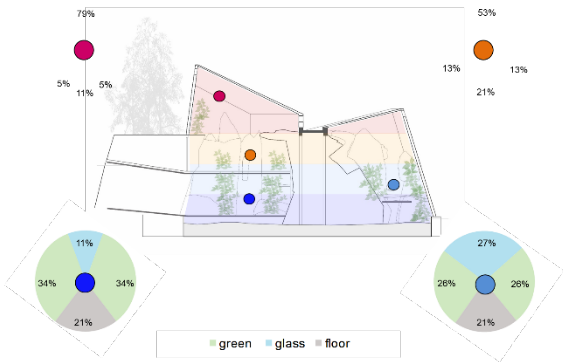

Figure 12 View factors established for the modelling with dynamical thermal simulation.

Calibration of the digital twin based on the measurement results.

All these findings have been used to calibrate and verify the TRNSYS 3D multizone model which was then used for further thermal and design optimization of the new glasshouse. The model also included an approach to model the vegetation within the greenhouse.

Without consideration of shading by green lower air temperatures are needed to compensate for the missing radiant comfort. Taking this approach for system layout would increase the cooling capacity. Oversizing the cooling typically creates control issues for humidity and temperature and increases the energy demand. Often thermal comfort is too cool, and people feel uncomfortable.

Considering the shading effect by trees in the cool house, the air temperatures can be relaxed. Excellent growing conditions are created, and the thermal comfort of visitors is improved.

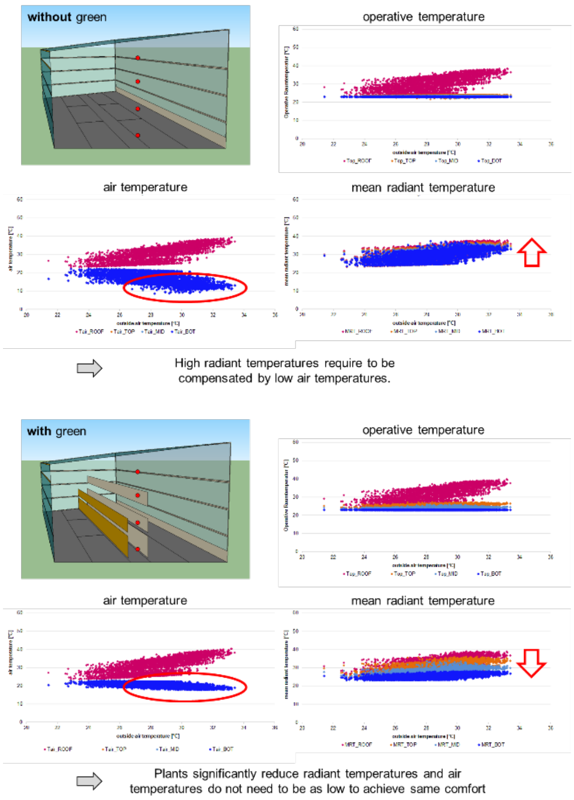

Figure 13 Results of thermal modelling, Top: without consideration of shading by green, Bottom: With the shading effect by green

Evaluation of illumination distribution within the Cool House

In addition to all the thermal modelling, daylight and solar modelling of different light levels have been done for inside and outside the building.

To assure, that all vegetation inside the building will receive sufficient daylight, detailed daylight simulations were carried out. This was achieved through modelling light levels as well as PAR-levels (Photosynthetically Active Radiation) on all surfaces of the modelled landscape within the space. The results have been used to optimize the landscape and positioning the plants.

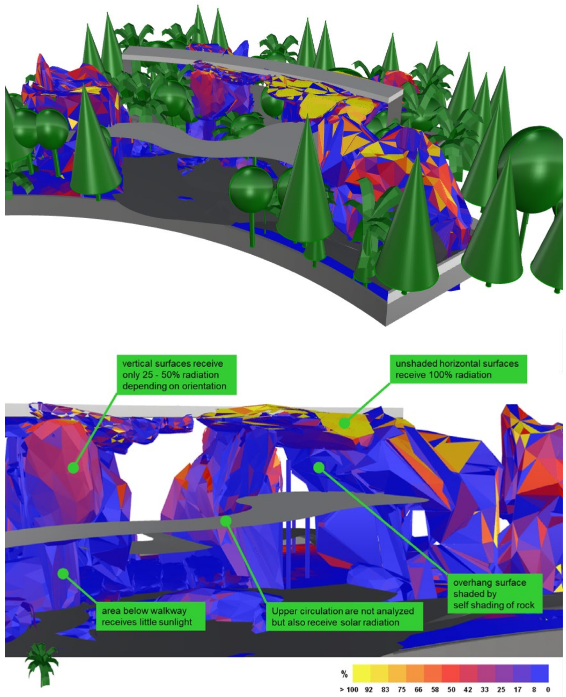

Figure 14 3D dynamical PAR spectrum analysis with consideration of trees

Simulations were carried out for bright sky conditions with sun for the 21st of March from 11 am to 4 pm in hourly steps for Singapore location with and without trees. The accumulation of lux-levels for each receiver point results in klux-hours, which is an indicator for accumulated illumination for a certain period. The reference is a horizontal receiver point that is located below the glazed roof and is unshaded by rocks or other elements and therefore the maximum possible. The applied metric is the ratio of klux-hours per receiver point divided by klux-hours of the reference receiver point in percent. That means a receiver point that is indicated with 50%, receives 50% of the accumulated illumination compared to the unshaded reference.

Acknowledgments

Client: NParks, Singapore

Architects: CPG, Singapore

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Credits Figure 1: Finbarr Fallon, Singapore