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The architectural implications of adopting low exergy cooling strategy: separation of sensible and latent cooling

Chen Kian Wee[1,*], Arno Schlueter[2] and Patrick Janssen[3]

[1]Future Cities Laboratory, Singapore-ETH Centre for Global Environmental Sustainability, Singapore
[2] Ass. Professorship of Architecture and Sustainable Building Technologies (SuAT), ETH Zurich, Switzerland
[3] Department of Architecture, National University of Singapore

Corresponding email: kian.chen@arch.ethz.ch

ABSTRACT
The Separation of Sensible and Latent Cooling Load (SSLC) is an appropriate low exergy cooling strategy for the tropical climate. The cooling process consists of two main components; the latent and sensible cooling. Latent cooling is exergy intensive where 8°*C is used for the removal of moisture from the air by condensation. For sensible cooling only around 18*°*C for the removal of heat from the space are required. However, in conventional practice these two processes are often combined as part of an air-based cooling system. As a result 8*°*C is used for both processes resulting in a higher exergy consumption. This paper proposes the implementation of SSLC as an alternative cooling method. Alongside this, promotes the change from an air-based to a hydronic, high temperature cooling system for the delivery of sensible cooling. Furthermore, to reduce exergy losses due to the transport of dehumidified air within the building, decentralized ventilation is advocated. This work addresses potential architectural implications of employing such a strategy and the related technologies to achieve exergy efficient buildings. A series of design scenarios using a sample building shows that it is essential for the architect to consider the related system parameters in the early design stage where adjustments to the design can still be easily made.*

KEYWORDS: *Sustainable Building, Low Exergy, Integrated Design, Separation of Sensible and Latent Cooling, Architectural Design Process, Environmental Simulation*

1 INTRODUCTION

The concept of exergy describes the quality of an energy flow. The concept was originally used for the assessment of power stations to maximize the power output. Recently, it was used for the analysis of cooling and heating in buildings (Shukuya and Hammache, 2002). In the case of cooling a building, the main aim is the removal of heat from an interior space. This can be achieved using different mediums at different temperatures. Exergy efficiency in this context is related to the temperature difference between the supplied medium to cool down the space, dehumidify the supply air and the heat rejection; the smaller the temperature difference the higher the performance of the chiller and the less exergy is required for running the chiller (see Equation (1) and (2)). To exergetically assess the cooling process, one needs to investigate the two main components of cooling, sensible and latent.
The latent cooling is the dehumidification of the fresh air supply, while the sensible cooling is the removal of heat from the occupied space. Latent cooling is an exergy intensive process since a temperature of 8°C is required to remove the moisture from the air through condensation. Given sufficient large cooling surfaces, sensible cooling only needs about 18°C to keep the occupied space at 25°C.
The Separation of Sensible and Latent Cooling Load (SSLC) is a very appropriate low exergy strategy in the tropical climate (ECBCS, 2011). Research had been conducted to assess the feasibility of SSLC through simulation models (Hwang et al., 2010; Ling et al., 2008) and SSLC had been implemented in buildings such as the ST Diamond building in Kuala Lumpur (Reimann, 2012). In Singapore the minimum fresh air supply for an office space is 5.5 l/s per person (SS553, 2009), the latent load can amount to about 30%~40% of the total cooling load, thus by separating the two processes bears the potential for significant energy savings.
The performance of a chiller (heat pump) is limited by its Coefficient of Performance (COP); the COP is dependent on the temperature lift between the supply temperature and the heat rejection temperature. The supply temperature is the temperature needed to perform the cooling task; where it is 8°C for latent and 18°C for sensible cooling. The heat rejection temperature is equal to the surrounding air temperature and can be assumed to be 32°C in Singapore. This relationship is reflected in equation (1).

$$COP_{real} = g \bullet \frac{T_s}{T_r - T_s} \tag{1}$$

Where g is the Carnot factor, it is usually around 0.4~0.5. T_r is the heat rejection temperature and T_s is the supply temperature in (K). In equation (1) the minimization of the temperature difference between T_r and T_s will improve the COP of a chiller. According to equation (2) the exergy input is reduced by increasing the COP of the chiller.

$$Ex_{in} = \frac{Q_r}{COP} \tag{2}$$

Where Ex_{in} is the exergy input to remove the heat, which is usually supplied in the form of electricity. Q_r is the amount of heat removed also called cooling energy in (J). Conventional practices delivers the cooling through an air-based system, due to this a temperature of 8°C is used for both latent and sensible cooling. For SSLC two chillers are used; one responsible for sensible and the

other for latent cooling. For the provision of sensible cooling the COP of a chiller is significantly increased due to the lowering of the temperature difference between the supply and heat rejection temperature, which in turn, significantly reduces the exergy input.
This paper briefly describes the building systems necessary to implement SSLC strategy in the tropical climate. The focus is on the resulting influences on architectural design and the impact of the prevalent architectural design process by considering active system already in the design stage. A case study inspired by the design of the SANAA Zollverein School of Management and Design (Basulto, 2010) is employed to illustrate the benefit of SSLC. Lastly, the challenges of such a design process and how it is a step towards an integrative design approach will be discussed.

Building Systems

The two main building systems that are used in practice and considered in this work are radiant panels and decentralized ventilation units (Figure 1). The radiant panels are responsible for the sensible cooling and belong to the category of high temperature cooling systems. It is a hydronic system where 18°C water is supplied to the panels to create a cool surface. The cool surface cools the occupants through radiant exchange and air convection. Water of 18°C provides a heat removal rate of 50W per cooling surface area (ASHRAE, 2002). The cooling capacity of the radiant panels is dependent on the amount of surface area available, the heat removal rate and cooling load as described by equation (3).

$$\dot{Q}c = A_c \bullet q_c \tag{3}$$

Where $\dot{Q}c$ is the cooling capacity of the radiant panels in (W). A_c is the area of the cooling surface in (m^2) and q_c is the heat removal rate in (W/m^2). According to equation (3) the cooling capacity is dependent on the cooling surface available which is usually the ceiling area. First of all, the sensible cooling load needs to be within the cooling capacity. It is influenced by the envelope quality, orientation, shading and the Window Wall Ratio (WWR) of the building. In order to meet the cooling load, enough surface area needs to be allocated to have enough cooling capacity. The architect has to balance the cooling load and the cooling capacity at the architectural design stage where alterations can still be easily made.
Due to the high humidity in the tropical climate, condensation on the radiant panels is an issue of major concern. The air tightness of a building envelope comes into question when such a system is proposed. The use of similar systems such as the cool slab has been successfully implemented in the ST Diamond building, the Green Energy Office (GEO) building ("Green Energy Office (GEO)," 2007, "ST Diamond Building," 2010) and "Gardens by the Bay" in Kuala Lumpur and Singapore respectively. The architectural concern is that a space that is conditioned by radiant panels should not be directly exposed to an unconditioned space, as the moisture from the unconditioned air will condense on the panels due to the cold surface.
Dehumidified fresh air is provided by the decentralized ventilation unit. Decentralization reduces the pressure loss within the air distribution system, which is achieved by placing the unit close to the façade to draw air from the outside and directly deliver it to the occupants. The ventilation unit can be integrated into building elements such as the floor slab or placed under a raised floor. While providing dehumidified fresh air, 40-50% of the sensible load is already removed from the space. This percentage of the sensible load is dependent on the amount of fresh air needed, which is determined by the occupancy. For some usages such as an auditorium, SSLC is not beneficial as the amount of required fresh air already provides adequate sensible cooling. In this paper, the requirements of office spaces are used.
Figure 2 is a schematic diagram showing one of different options of how the building systems can be integrated into the architectural design. The decentralized ventilation unit and the ducting are embedded into the floor slab. The air intake and exhausts are located at the window sill, where it is not visible from the elevation of the façade.

(a) (b)

Figure 1(a) radiant panels (b) decentralized ventilation unit

The implementation of SSLC needs a holistic design approach, where architecture elements such as building envelope, orientation, shading, WWR and program of a space have a direct impact on the feasibility of the cooling strategy. Active systems need to be factor into the design process, so that an architect is aware of the impact of his design actions on the cooling strategy and vice versa. The challenge for the architects lies in the acquisition of all the necessary information for making design decisions in the early design stage.

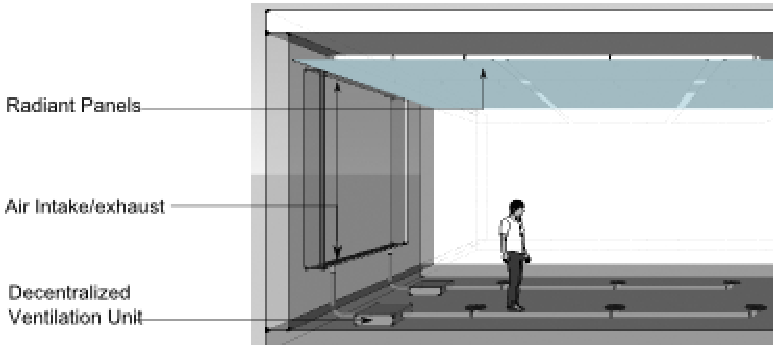


Figure 2 Integration of building sytems

Architecture Design Process

The prevalent architectural design process for energy efficient buildings is primarily focused on optimizing the passive aspect of a building. However, according to the Building Construction and Authority (BCA) Green Mark assessment scheme in Singapore (BCA Singapore, 2013), to achieve a Green Mark Platinum building one needs to satisfy an Envelope Thermal Transfer Value (ETTV) (Chua and Chou, 2010a, 2010b) of 40W/m^2 and a chiller COP of about 5.4. Therefore, if an architect wants his building to be accredited it would be beneficial for him to also consider the active systems. Instead of leaving everything to the mechanical engineers, architects should assume a certain responsibility to ensure an efficient cooling strategy for the building. Although the COP of a chiller is dependent on many systems variables, an architect can contribute by reducing the temperature lift and designing a favorable environment for the cooling system to achieve a high COP.

Furthermore, looking at only the passive systems greatly limits the architectural expression of a design as the building envelope is a main component of the building aesthetics (Ritter and Meggers, 2010). By also paying attention to the active systems in the architectural design stage, the architect is able to control and balance his architecture intention while realizing an energy efficient building. Usually architects are more comfortable with the manipulation of geometry, material and space in a design process and are unfamiliar with active systems. In order to facilitate the consideration of active systems in the architecture design stage, the use of energy simulation programs would be necessary to offer feedback to an architect's design decision.

The use of environmental simulation programs in the design process has been extensively studied in the architecture field (Augenbroe et al., 2004, 2003; Citherlet et al., 2001) and tools are readily available to facilitate this design process. A few examples include Rhinoceros3D/grasshopper with Energyplus and Radiance (Lagios et al., 2010), Houdini3D with Energyplus and Radiance (Janssen et al., 2011) and Revit Architecture with EnergyPlus (Sanguinetti et al., 2012; Schlueter and Thesseling, 2009). The environmental simulation programs used in these examples are energy simulation and daylighting simulations.

For implementing SSLC the architect needs to obtain the cooling loads of his design using an energy simulation program. For the cooling load, the heat removal rate for the radiant panels can be derived from equation (3) and from the heat removal rate we can obtain the supply temperature. The permissible temperature range is about 16°C to 20°C. If a temperature below 16°C is used there is a high possibility of condensation on the panels and the high temperature difference between the panel and the occupant's body temperature will cause discomfort to the occupants. If the temperature is higher than 20°C there might not be enough cooling capacity to keep the space at 25°C. The COP of a chiller can then be calculated using equation (1). Lastly, according to equation (2) the exergy input for sensible cooling can then be calculated. These steps are repeated for calculating the exergy input for latent cooling, where a supply temperature of 8°C is used.

The low exergy design process introduces a new layer of complexity by including the active systems in the architecture design process. The various parameters of passive and active systems are illustrated in Figure 3. According to equation (3) if the sensible cooling load exceeds the cooling capacity that is available from the panel surface area then it is not possible to implement SSLC. The sensible cooling load is related to the thermal properties of the wall constructions and glazing, WWR, shading and the orientation of a design, so the passive aspects still plays a major role in the low exergy design process. The low exergy design process offers strategies that do not directly affect the building envelope, however this is only possible if the sensible cooling load stays within the cooling capacity of the panels. One can increase the supply temperature by increasing the panel surface area or reduce the heat rejection temperature by using cooling towers, which will reduce the temperature lift and increase the COP and in turn decrease the exergy input. The dependency of the active system on the passive system further complicates the design process as compared to the more straightforward prevalent design process.

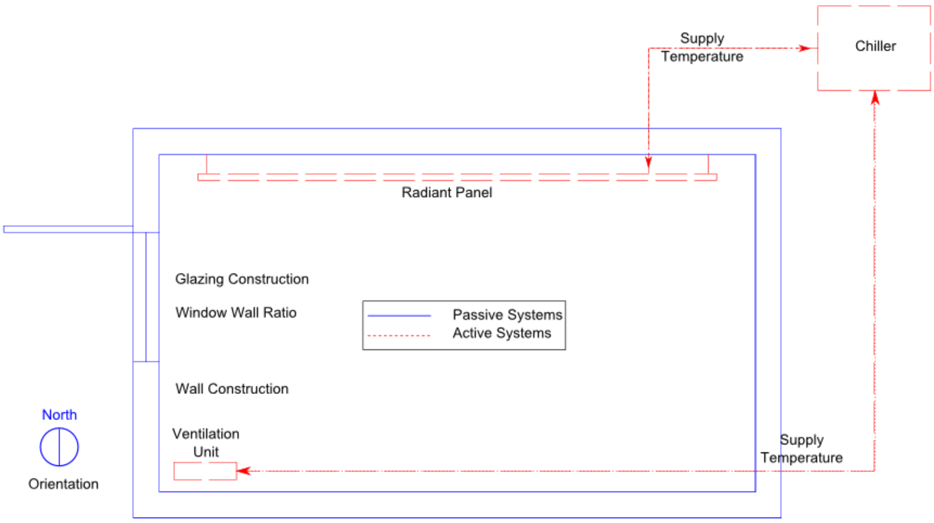


Figure 3 Active and Passive System Components

2 DEMONSTRATION

Design Scenario

A design scenario based on SANAA Zollverein School of Management and Design (Basulto, 2010) was used to demonstrate the low exergy design process. For the demonstration, the building was placed in Singapore. The Zollverein School is a 35x35x35 meter cube, the façade consisting of windows of four different dimensions. The initial design punctured the concrete exterior wall with numerous apertures and it consisted of hundreds of windows, but had to be altered to the current design due to cost and structural considerations.

Using the realized design, a 3D model was constructed for energy and daylighting simulations. The wall and glazing was assigned with typical construction properties of a Singapore office building. The insulated concrete wall has a U-value of $2W/m^2K$ and the double-glazing window without any LowE coating has a U-value of $2.8W/m^2K$ and a shading coefficient of 0.81. The solar heat gain was calculated using the ETTV and the typical occupancy, plug and lighting load were added to get an estimation of the cooling load. The exergy input for cooling was then calculated. A Radiance lighting simulation (Ward, 1994) was conducted with cloudy sky settings to obtain the daylight levels of the interior. The daylighting performance was expressed as the ratio of the floor area receiving more than or equal to 300 lux over the total floor area. This configuration has been used as the base case scenario for comparison as the design was improved gradually.

Passive Improvements

In a first step, the performance of the design was improved through alterations of its passive systems, namely the improvement of the building orientation, the wall and glazing construction and the addition of shadings. The addition of shadings to the glazing is a highly effective strategy to reduce solar heat gain in the tropics and the increase in thickness of the wall construction to have better thermal performance reduces the heat transmitted into the space through conduction. Most of these improvements have a large impact on the aesthetics of the building.

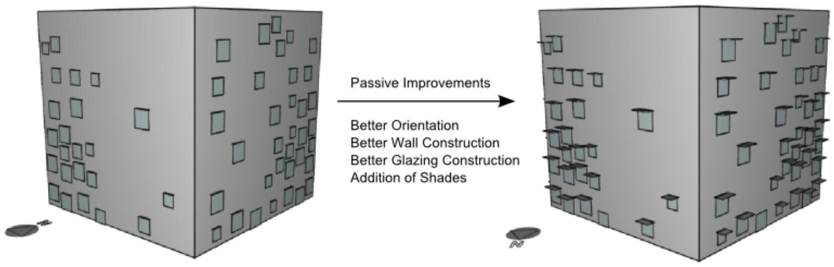
Five designs have been simulated for their performance. A summary of the designs is provided in Table 1. The cooling load was obtained as mentioned in previous section and using equation (1) to (3) the exergy input for cooling was calculated using a supply temperature of $16^{o}C$(70W/m2) to $18^{o}C$(50W/m2) depending on the cooling capacity required for the sensible load and $8^{o}C$ was used to calculate the exergy input for the latent load. Design 1 is the base case scenario with a daylighting performance of 42% and a cooling exergy input of 55.7kWh/m2/yr. For Design 2 the passive system was optimized with a better construction, a different orientation and the addition of 1.5m deep horizontal shadings at each window. Design 2 performed significantly better with about a 12.7kWh/m2/yr reduction in cooling exergy input. A comparison between the two designs is shown in Figure 4. However, due to the addition of shadings the daylighting performance dropped drastically to 27.4%. This is a common dilemma faced by architect in design, where the increase in performance of one aspect leads to the decrease in another. A conventional air-based cooling system was used for both the design and a COP of 4.6 was achieved.

Active Improvements

Design 3 is similar to Design 1 but uses a SSLC system. The cooling exergy input decrease from 55.7 $kWh/m^2/yr$ to 36.4 $kWh/m^2/yr$ (Figure 5). This is due to the much higher efficiency of the SSLC system as compared to a conventional air-based system. The overall COP increase from 4.6 to 6.3. The building envelope does not need to be altered to improve the exergy performance and the original architecture intention remains unchanged. However, the implementation of SSLC does requires attention to the construction details in order to integrate the cooling system into the building. This is shown in Figure 2.

Table 1 Design Scenarios

Description	Concrete wall U-value (W/m2K)	Glazing U-value (W/m2K) & Shading Coefficient	Orientation (° anti-clockwise)	Shading (m)	Window Wall Ratio	Cooling system
Design 1 (base case)	2	2.8, 0.81	0	0	0.22	Air-based
Design 2	1.11	1.55, 0.54	225	1.5	0.22	Air-based
Design 3	2	2.8, 0.81	0	0	0.22	SSLC
Design 4	2	2.8, 0.81	225	0	0.25	SSLC
Design 5	1.11	1.55, 0.54	225	0	0.25	SSLC



Design 1	Description	Design 2
55.7	Exergy Input (kWh/m2/yr)	43
42	Daylighting (%)	27.4
57	ETTV (W/m2)	27.7
323.5	Sensible Load (kW)	216.5
144.1	Latent Load (kW)	144.1
8	Supply Temperature (Sensible) (°C)	8
8	Supply Temperature (Latent) (°C)	8
4.6	COP (Sensible)	4.6
4.6	COP (Latent)	4.6
4.6	COP (Overall)	4.6

Figure 4 Comparison of Design 1 and Design 2

In an attempt to further improve the daylighting performance, in Design 4 the WWR is increased from 0.22 to 0.25 and is orientated 225° anticlockwise to receive better daylighting. The daylighting level is increased to 50.3%, while the cooling exergy input increased by 1.3kWh/m^2/yr as compared to Design 3. The increase was dampened by the efficiency of the cooling system, thus giving an advantage for the architect to balance the performance of two contradicting aspects of design. Even without the high performance constructions and shadings, Design 4 is able to outperform Design 2 both concerning daylighting and cooling exergy input (Figure 6).

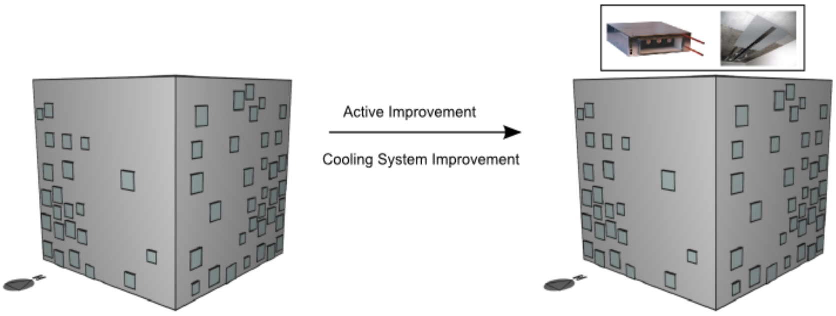
Active and Passive Improvements

When only one system is optimized at a time, none of the design was able to satisfy the Green Mark Platinum criteria. Design 2 performed well in terms of the ETTV requirement with a 27.7W/m^2 but badly in terms of COP at 4.6, Design 3 had a high COP of 6.3 and an ETTV of 57W/m^2, while Design 4 had a high COP of 6.4 and an ETTV of 62W/m^2.

Design 5 is optimized passively and actively (Figure 7). The building envelope is constructed of insulated concrete wall of U-value 1.11 and LowE double-glazing of U-value 1.55 and Shading Coefficient of 0.54. The architectural intention was preserved, while a high level of performance was achieved for both daylighting level and cooling exegy input. The cooling exergy input was the lowest of the five designs, while the daylighting level performed 2.5% lower than Design 4 due to the use of LowE double-glazing glass. The ETTV was 39.7W/m^2 and the COP was 6.3. Design 5 satisfies the Green Mark Platinum criteria, at the same time it preserves the architectural intention and improved the daylighting performance of the design.

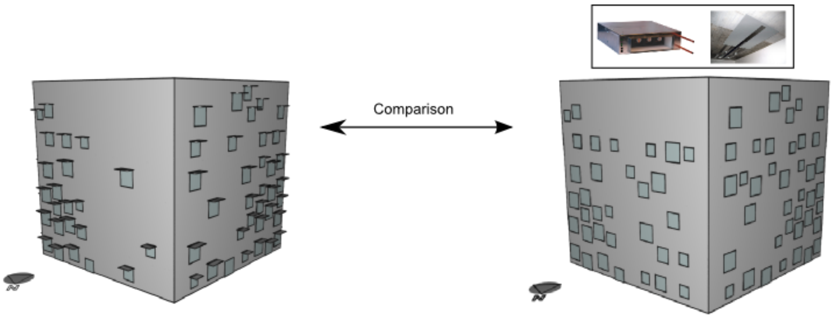
Some may argue that the systems could still be optimized individually by the architect and the engineer. However, the dependency between the active and passive systems will cause conflict to arise. For example, if an architect would like to further improve the daylighting performance, he will increase the WWR. This inevitably will increase the cooling load and affect the COP. By designing with the cooling system in consideration, he will be able to know how much more cooling load is permissible before his design actions will impede the implementation of the cooling systems.

In addition, the implementation of the radiant panels and decentralized ventilation units requires certain spatial consideration such as the cooling surfaces area and the program of the spaces. By considering the cooling strategy at the architectural design stage, the architect greatly facilitates the implementation of the cooling systems and at the same time ensures his design intention goes hand in hand with the cooling strategy



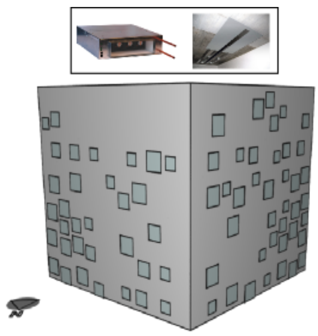
Design 1	Description	Design 3
55.7	Exergy Input (kWh/m2/yr)	36.4
42	Daylighting (%)	42
57	ETTV (W/m2)	57
323.5	Sensible Load (kW)	323.5
144.1	Latent Load (kW)	144.1
8	Supply Temperature (Sensible)(°C)	**17**
8	Supply Temperature (Latent)(°C)	8
4.6	COP (Sensible)	7.7
4.6	COP (Latent)	4.6
4.6	COP (Overall)	6.3

Figure 5 Comparison of Design 1 and Design 3



Design 2	Description	Design 4
43	Exergy Input (kWh/m2/yr)	37.7
27.4	Daylighting (%)	50.3
27.7	ETTV (W/m2)	62
216.5	Sensible Load (kW)	340.6
144.1	Latent Load (kW)	144.1
8	Supply Temperature (Sensible)(°C)	17
8	Supply Temperature (Latent)(°C)	8
4.6	COP (Sensible)	7.7
4.6	COP (Latent)	4.6
4.6	COP (Overall)	6.4

Figure 6 Comparison of Design 2 and Design 4



Description	Design 4
Exergy Input (kWh/m2/yr)	30.7
Daylighting (%)	47.8
ETTV (W/m2)	39.7
Sensible Load (kW)	259.8
Latent Load (kW)	144.1
Supply Temperature (Sensible)(°C)	18
Supply Temperature (Latent)(°C)	8
COP (Sensible)	8.3
COP (Latent)	4.6
COP (Overall)	6.5

Figure 7: Design 5

Sensible Cooling Load and Radiant Panels

The cooling exergy input can be further reduced by adjusting the heat removal rate; which is related to the supply temperature, or the cooling surface area of the radiant panels. The parameters involved are shown in equation (3). This can only be achieved if there is sufficient cooling surface area available. In the example, the sample building had a ceiling area of 4900m2. As the panels are mounted on the ceiling, the area of the ceiling will restrict the amount of surface area available for installing the panels.
The supply temperature used in Design 5 is 18℃. For Design 6, the supply temperature is increased to 19℃, thus increasing the COP of the chiller according to equation (1), in turn reducing the sensible exergy input. The amount of cooling area needed in Design 6 will then be 4405m2, which is still within 4900m2 and the COP will increase to 9.4. To further reduce the sensible exergy input the supply temperature is increased to 20℃ in Design 7, which leads to a required cooling surface area of 5662m2 and a COP of 10. Since this exceeds the ceiling area available, one could improve the quality of the building envelope construction in order to reduce the cooling load.

Table 2 Parameters determining the implementation of radiant panels

Description	Supply temperature (℃)	Heat removal rate (W/m2)	Cooling surface area (m2)	Sensible load to be removed by the panels (kW)	COP (Sensible)
Design 5	18	50	3964	198.2	8.7
Design 6	19	45	4405	198.2	9.4
Design 7	20	35	5662	198.2	10.1

3 DISCUSSION AND CONCLUSION

The design scenario used in this work is a conceptual implementation of SSLC, so the results from the simulations are only indicative of an actual building. Further studies need to be conducted to validate this design approach. The BubbleZERO laboratory at the Future Cities Laboratory is a result of the low exergy design process. Currently, experiments are being conducted to measure the effectiveness of such an approach. The results from the experiments will feedback into the design process to strengthen the performance claims of the low exergy design method.
The main aim of this research is to bring forth this new approach in architectural design in the tropics and outline its related principles and building systems. This example shows the advantage of factoring in active systems considerations in the architecture design stage. The architect can incorporate cooling strategy into his design and create a favorable environment for the implementation of high performance active systems. Moreover, in order to satisfy the Green Mark Platinum criteria it is essential to consider the cooling systems in the design process, as it allows the architect more negotiation power in balancing between the architecture intention, the daylighting and energy performance. It also shows that the orientation, constructions and shading of a building are of far less importance in the reduction of cooling exergy input as compared to the usage of a more efficient cooling strategy. Although the cooling load is directly link to the passive systems, the extra cooling load induced by a lower quality building envelope can be compensated with an effective cooling strategy such as SSLC.

Low Exergy Design Support Tool

The challenge for an architect to adopt the low exergy design approach lies in the lack of information and data about the cooling systems of a design at the schematic design stage. This is addressed with the use of energy simulation programs. The topic of design and energy simulation has been extensively studied and there are commercial software packages in the market. However, the running of an energy simulation is still a difficult task especially in the schematic design stage, where a great amount of information about the building is still not available.
In order to support the low exergy design approach, including the relevant systems parameters; such as the supply temperature for the radiant panels, the required cooling surface and the number of ventilation units, digital design tools are being created to support integrated design decision-making. Various 3D modeling, lighting simulation and energy simulation programs are linked together in a workflow management program to ensure a smooth exchange of information (Chen et al., 2012a). An initial workflow was created (Chen et al., 2012b), but it needs to be further refined and validated alongside the low exergy design method. Such an environment will allow architects to test out various design options and obtain essential systems information for implementing SSLC. Through this the architect will be able to understand the relationship between the various parameters, envelope, structure and building system to the cooling exergy input.

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REFERENCES

[1] ASHRAE, 2002. ANSI/ASHRAE Standard 129-1997 (RA 2002), Measuring Air-Change Effectiveness. American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc., Atlanta, Georgia.

[2] Basulto, D., 2010. Zollverein School of Management and Design / SANAA [WWW Document]. Archdaily. URL http://www.archdaily.com/54212 (accessed 6.20.13).
[3] BCA Singapore, 2013. BCA Green Mark for New Non-Residential Buildings Version NRB/4.1.
[4] Chen, K.W., Janssen, P., Schlueter, A., 2012a. Performance Driven Design Optimisation with Scientific Workflow System. Presented at the Green Building Optimization Design, ASME, Shengyang, China, pp. 189–196.
[5] Chen, K.W., Schlueter, A., Janssen, P., 2012b. Optimisation of low exergy architecture in the tropics. Presented at the Sustainable Future Energy 2012 and 10th SEE Forum, Innovations for Sustainable and Secure Energy.
[6] Chua, K.J., Chou, S.K., 2010a. An ETTV-based approach to improving the energy performance of commercial buildings. Energy Build. 42, 491–499.
[7] Chua, K.J., Chou, S.K., 2010b. Energy performance of residential buildings in Singapore. Energy 35, 667–678.
[8] ECBCS, 2011. Low Exergy Systems for High-Performance Buildings and Communities Annex 49 Guidebook: Summary report. ECBCS, Nobelstraße 12 D-70569 Stuttgart Germany.
[9] Green Energy Office (GEO) [WWW Document], 2007. . Ien Consult. URL http://www.ien.com.my/projects/geo.html (accessed 7.7.13).
[10] Hwang, Y., Kuwabara, O., Ling, J., Radermacher, R., 2010. Enhancement of the Separate Sensible and Latent Cooling Air-Conditioning Systems. Presented at the International Refrigeration and Air Conditioning Conference.Paper 1068, Purdue.
[11] Janssen, P., Chen, K.W., Basol, C., 2011. Iterative Virtual Prototyping: Performance Based Design Exploration. Presented at the ECAADE 2011, pp. 315 – 322.
[12] Lagios, K., Niemasz, J., Reinhart, C.F., 2010. Animated Building Performance Simulation (ABPS) - Linking Rhinoceros/Grasshopper with Radiance/Daysim. Presented at the SimBuild, New York City.
[13] Ling, J., Hwang, Y., Radermacher, R., 2008. Theoretical Study on Separate Sensible and Latent Cooling AirConditioning System. Presented at the International Refrigeration and Air Conditioning Conference.Paper 902, Purdue.
[14] Reimann, G., 2012. ST Diamond Building Sustainability by Integrated Design.
[15] Ritter, V., Meggers, F., 2010. Assessment of the guidelines for zero-emission architectural design. Presented at the Clima 2010- 10th REHVA World Congress, Antalya, Turkey.
[16] Sanguinetti, P., Abdelmohsen, S., Lee, JaeMin, Lee, JinKook, Sheward, H., Eastman, C., 2012. General system architecture for BIM: An integrated approach for design and analysis. Adv. Eng. Informatics 26, 317–333.
[17] Schlueter, A., Thesseling, F., 2009. Building information model based energy/exergy performance assessment in early design stages. Autom. Constr. 18, 153 – 163.
[18] Shukuya, M., Hammache, A., 2002. Introduction to the Concept of Exergy – for a Better Understanding of Low-Temperature-Heating and High-Temperature-Cooling Systems. IEA ANNEX37 Low Exergy Systems for Heating and Cooling of Buildings.
[19] SS553, 2009. Code of Practice For Air - conditioning and mechanical ventilation in buildings, 2nd revision. ed. SPRING Singapore, Singapore.
[20] ST Diamond Building [WWW Document], 2010. . Ien Consult. URL http://www.ien.com.my/projects/st.html (accessed 7.7.13).
[21] Ward, G.J., 1994. The RADIANCE Lighting Simulation and Rendering System. Presented at the Computer Graphics 94 SIGGRAPH, pp. 459–72.