Technology Invigorating Architecture

Integrating passive and active systems to increase design freedom and environmental performance of buildings

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FCL Research Module:
Low Exergy

There is a growing desire to design buildings that address concerns about energy consumption, global warming and environmental impacts. This has led to widespread adoption of concepts like green buildings and ecological design, especially in places like Singapore, where green is rapidly becoming a symbol of status and quality design. But we must ask ourselves how these concepts are defined.

Active vs passive solutions

What does it take to produce a "green" building design? Many designers suggest a move away from technical systems, and a return to passive building design, re-discovering and re-evaluating vernacular design features like the building orientation to sun and wind. A popular way to achieve green currently in Singapore is to add greenery (Chua, 2013), green roofs and vertical greenery – the extension of the Garden City from the urban to the building scale. As ecological aspects of design they help shade surfaces, absorb storm water and ameliorate the outdoor microclimate, but their impact on the performance of a building – its resource consumption, energy use, and greenhouse gas emissions – is negligible.

This move toward passive systems as green strategies is quite common among architects and planners. It goes beyond the cliché of making the building green with plants, and it does incorporate important design strategies like appropriate and effective shading systems, daylight maximisation and natural ventilation optimization. Nevertheless, the focus on passive systems has led to a simultaneous neglect of the significant impact of the active systems, which still remain due to comfort expectations by users, regardless of any desire to eliminate these systems and move toward

Fig. 01 Model of a Low Exergy design approach

passive architecture. In Singapore, an excellent design for cross-ventilation, even on a high story, will only receive adequate air movement for comfort for roughly half the year as shown in Fig. 02 (ASHRAE, 2001). The other half of the year, the user will be left desiring an active system. This is never addressed when architects present their passive solutions in Singapore. More often than not the failure of airflow will not lead to the purchase of a simple active and highly energy-efficient fan, but rather a split type air-conditioner, and even in condos designed for passive ventilation, split units are installed by default. Ironically, conscientious building users with air-conditioning will now keep the windows closed to reduce energy wastage, voiding any benefit of cross ventilation. Although the closed windows limit energy wastage from air-conditioning, a fan can run with up to 1000 times less energy than a common room air conditioner, yet this option is often skipped over when going switching from a passive to an active system.

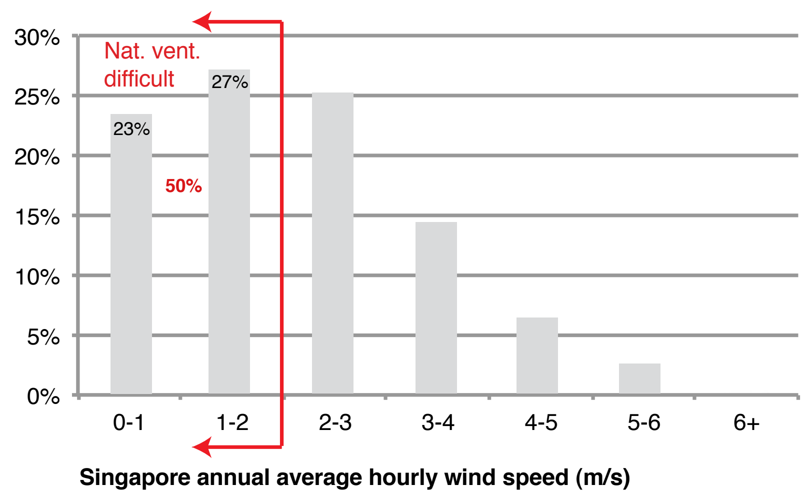

Fig. 02 Distribution of wind speeds in Singapore over the year: Even if designed for cross-ventilation, the speed of the air movement inside the building will only be a fraction of the wind speed

At the same time, many engineers look at the same building and see only the potential of increasing the machine efficiency. The focus is often only on providing enough capacity to cool the room to a maximum of 22 °C, and doing so using the most efficient refrigeration system possible. Over the last 25 years, average chiller efficiency has increased by 35%, which may seem like a lot, but by considering the entire cooling system including operation temperatures, we can increase performance by more than 40% (Meggers, Baldini, et al., 2012; Bruelisauer, Chen, et al., 2013), and when we combine novel ventilation and dehumidification techniques we have the potential to double the performance (Meggers and Bruelisauer, 2013).

In order to successfully move to building designs that significantly reduce the environmental impact, it is essential to be aware of the potential of both passive and active systems. They can help or hinder the performance of a building in terms of both energy and comfort. By addressing both aspects of design instead of just passive (as architects often do) or just active (as engineers often do), we can achieve much higher levels of performance that go far beyond what each discipline feels is best practice today.

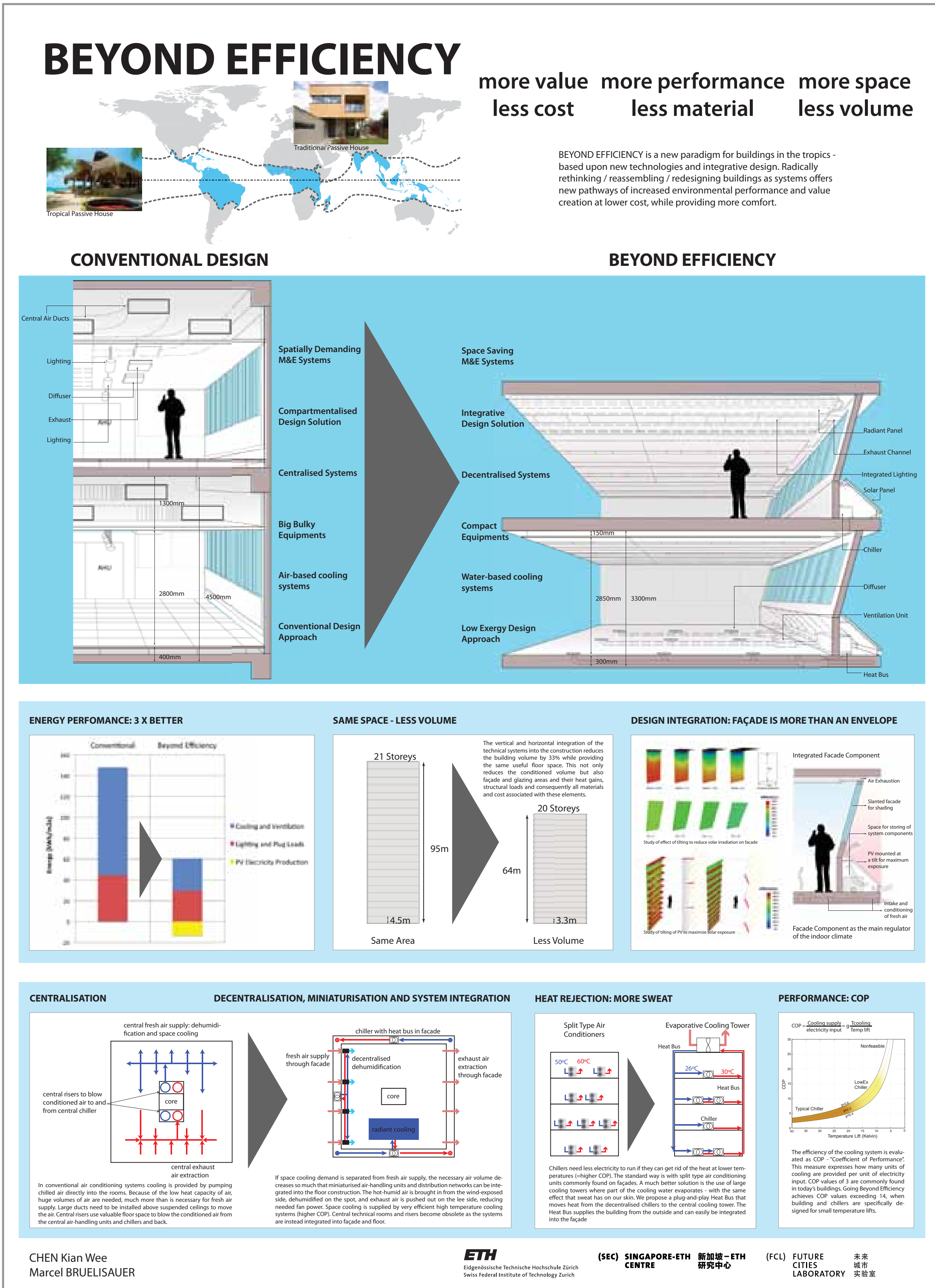

Fig. 03 Award winning contribution to the Student Poster Competition at the Holcim Forum for Sustainable Construction, Mumbai 2013

Better design freedom with the LowEx paradigm

In practice it is very difficult to apply such a broad set of expertise, we therefore attempt to instil an awareness that facilitates a collaborative development of building form and function, which considers aspects of aesthetic, performance and operation simultaneously. One of the tools we use to do this is the paradigm of low exergy design. LowEx design emphasizes the impact of design decisions on the overall system performance. Instead of considering the individual loss of energy through a wall, and the insulation that is needed to reduce it, the LowEx consideration would connect that loss to the energy supply chain, thereby evaluating the points in the chain to achieve maximum benefit. This may be back at the point of energy generation or at the point of supply, and not at the wall insulation. Exergy represents the essence of the energy that is necessary to drive the heart of the system.

The application of exergy to building system design has been around for the past few decades and was the focus of two International Energy Agency Annexes (IEA ECBCS Annex 37, 2003; IEA ECBCS Annex 49 ,2010). We have used the concept at the ETH Zürich to develop new systems (Meggers, Ritter, et al., 2012), and have popularized the paradigm of low exergy in Switzerland ("Neue Wege Zum Nachhaltigen Bauen", 2011; "Modellfall Sanierung HPZ", 2011; Röttele and Bachmann, 2011). An excellent example of the different perspective provided by the low exergy paradigm for building design is to consider the insulation of a wall. As shown in Fig. 04, as additional insulation is applied to a standard block wall, the reduction in heat transmission, and thereby building heat (or cool) demand diminishes. If 50 cm of insulation is added, not uncommon for a passive house design, then the last 10 cm of insulation added provides the exact same benefit as the first ½ cm that is added, a full 20x reduction in performance, even though the insulation itself remains the same.

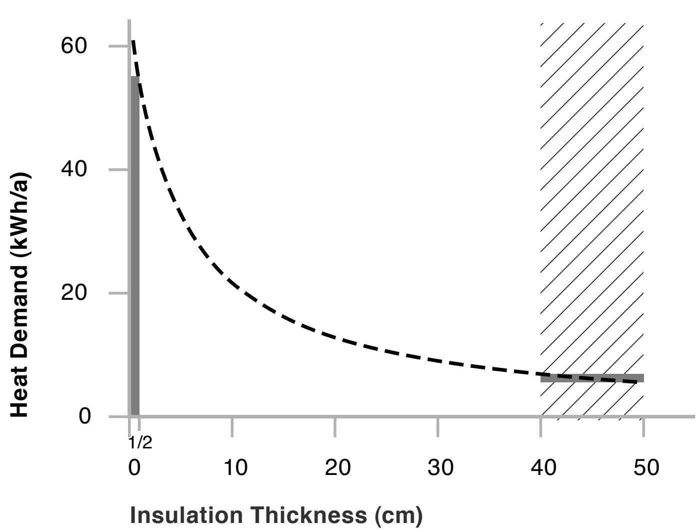

Fig. 04 Diminishing benefit of adding insulation to a building: the last 10 cm of insulation provides the same added benefit at the first ½ cm did. 50 cm represents the typical amount of insulation needed to achieve a passive house level of heat demand

By extending the perspective to beyond just the wall of the system to the overall demand, we can see that a high performance wall achieving the performance of the 'passive house' may not always be the most effective solution. It is not to say that the 'passive house' strategy is not an excellent way to reduce energy demand. From a systems perspective, the way it eliminates the need for additional heating systems is another example of how paybacks for good design may come in a different part of the operational chain of the building. But 'passive house' can be quite limiting, especially in the design of the shell, and many architects would feel restricted by the limits placed on aesthetic if 'passive house' would become the standard for façade design.

In Singapore the idea of 'passive house' is a completely different story. The typical 'passive house' cleverly uses internal and solar gains, omitting the need for a heating system, something that applies to the heating context only. The most 'passive house' that can be built in Singapore would be a beach pavilion with no walls, shaded from solar irradiation while maximizing the natural movement of air and its ability to provide comfort via convection. There are no internal "cooling gains" that could be leveraged to create a cooler indoor environment. In the tropics the same heat gains that make 'passive house' possible become the enemy; instead heat has to be constantly removed to the outside.

Uncovering new potential for the topics in Singapore

We have brought this LowEx design paradigm to Singapore and strive to develop new ways of providing adequate cooling and comfort in building spaces with minimal energy demand. We aim to eliminate prescriptive design strategies, which constrain design freedom, and create integrated technological solutions that instead invigorate architectural possibilities and awareness.

Our research aims first and foremost at demonstrating how air-conditioning can be provided with active systems that meet standard cooling demands with far less energy consumption. From that basis, we aim to demonstrate how better comfort can be achieved through integrating passive design strategies with active technical systems, which are themselves aware of the need for a broader definition of comfort and adapt to the spatial and functional context.

The first aim has been studied extensively in our *BubbleZERO* laboratory where we have implemented many LowEx building systems, such as radiant cooling and decentralized ventilation, and where we are evaluating the performance in the tropics (Bruelisauer, Chen, et al., 2013). Here is where we have confronted one of the largest challenges for tropical building design – humidity. Although temperature is the most widely reported comfort parameter, it is the humidity that is more relevant in the tropics. We have adapted our low exergy systems to address issues of humidity (Meggers, Baldini, and Pantelic, 2011; Iyengar, 2012; Saber, Meggers, and Iyengar, 2013), and we are optimizing their operation while considering new advanced systems for dehumidification that address critical issues in the system operation chain, again based on the LowEx approach.

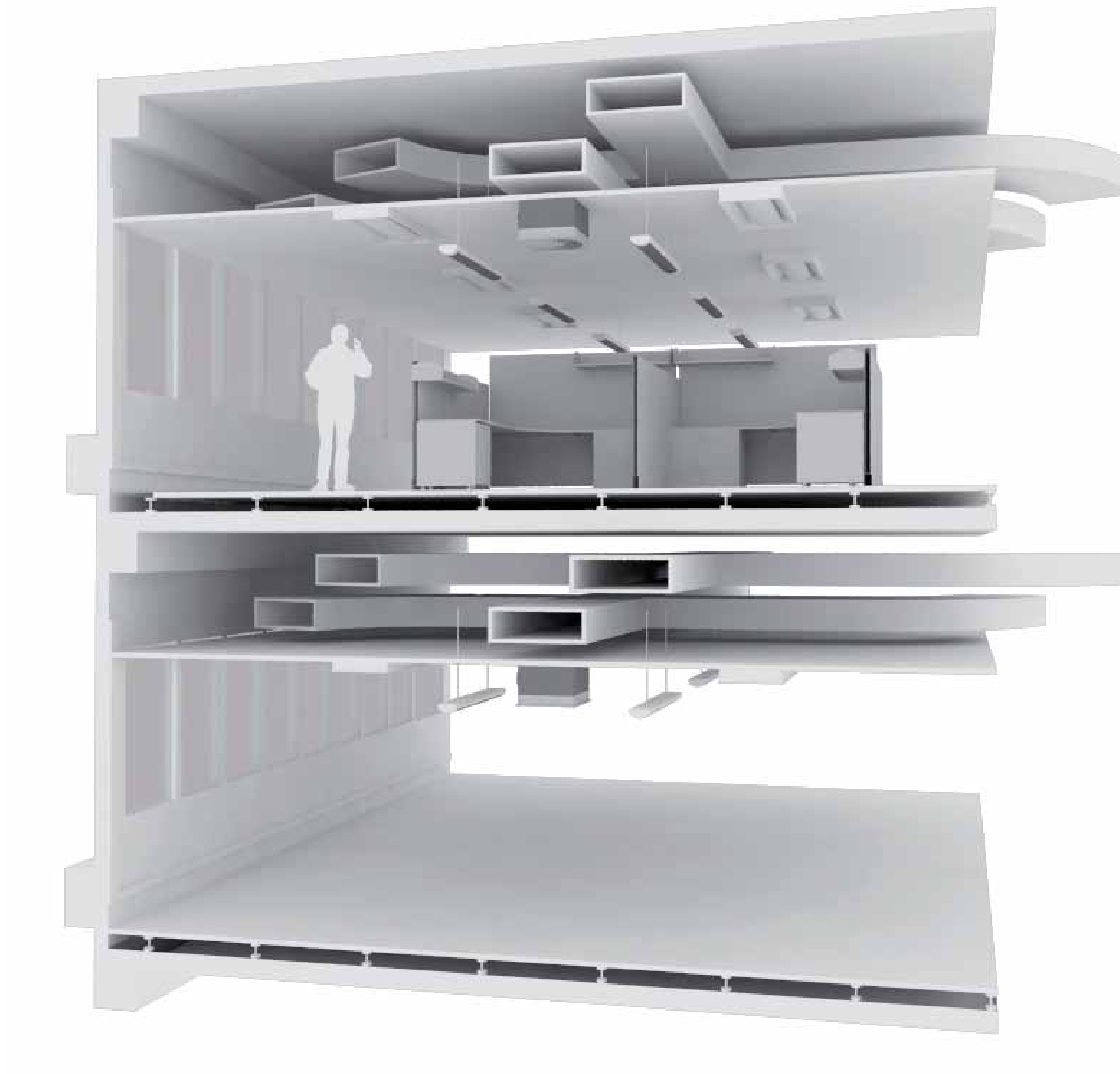

Fig. 05 Conventional design paradigm as observed in the Future Cities Laboratory office building at the campus of the National University of Singapore: The disconnected design paradigm leads to a spatial separation of functionality - structural and mechanical elements, fabric and interior design elements. Cooling is provided by pumping chilled air directly into the rooms. Because of the low heat capacity of air, huge volumes of air are needed, much more than is necessary for fresh air supply, resulting in large ducts installed above suspended ceilings and in central risers. 30% of the building volume is taken up by technical systems, space that is wasted for building users

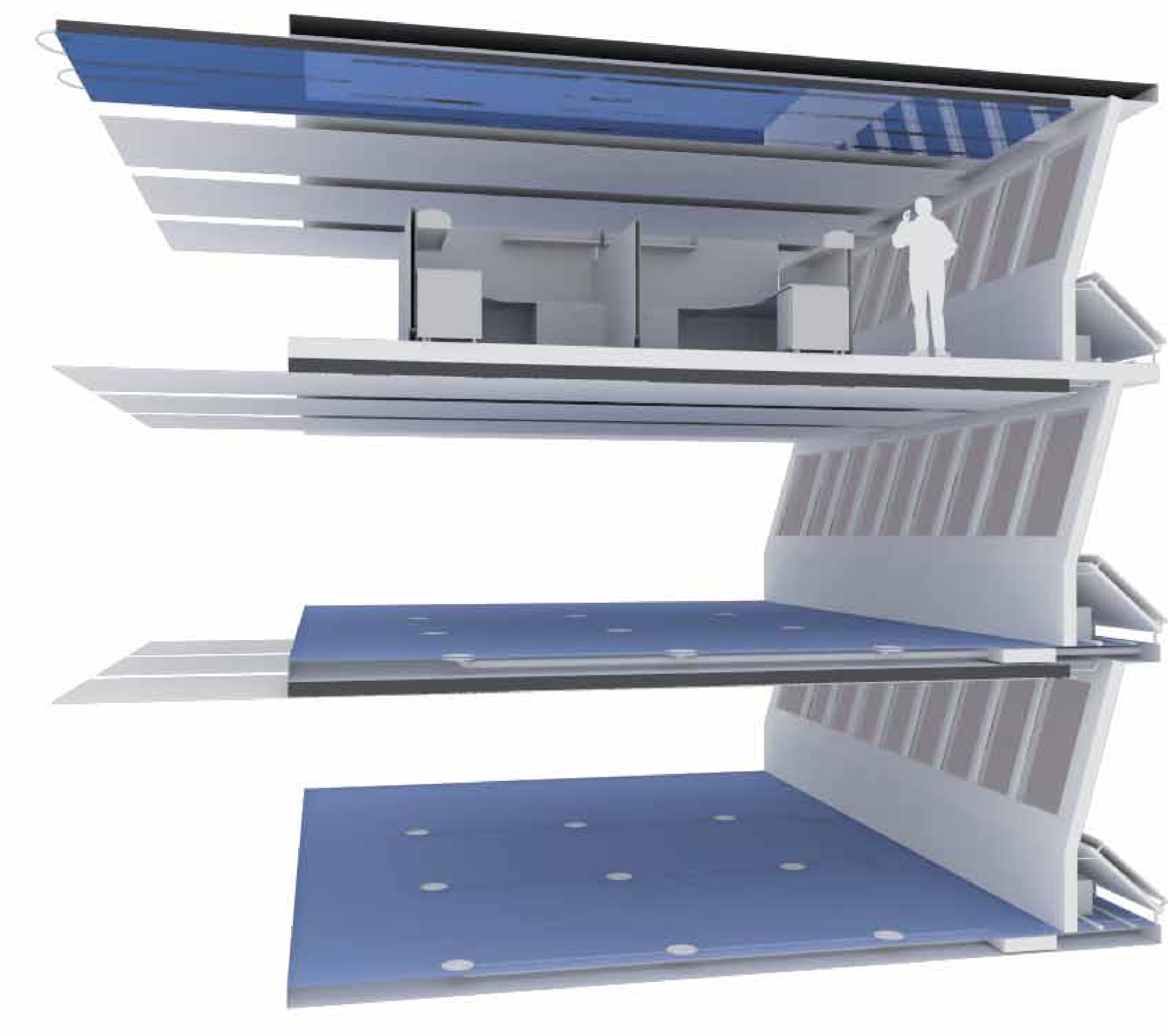

Fig. 06 LowEx design paradigm 342x, physically integrating active and passive elements: Using hydronic piping to thermally activate the concrete slab for space cooling, the necessary airflow for fresh air supply only is reduced so much that the ducting can be integrated into the concrete slab. Technical systems such as air intake and dehumidification, chillers and heat rejection are removed from the building core and integrated into the façade. This new design paradigm will result in a reduction of floor-to-floor height, achieving three floors for the space of two while increasing environmental performance. Less material use and less façade area will lead to additional indirect benefits such as smaller heat gains, ultimately driving down investment and operational cost and create more value

Our more recent success has been on the broader issue of active and passive system consideration. In the standard split type unitary air-conditioners installations we have uncovered a huge gap between designer intension and engineered system installation outcomes (Bruelisauer, Meggers, et al., 2013). These split units are prevalent in all hot-humid areas, available in almost any urban context where cooling might be required. Using novel wireless sensing technology we were able to record the temperature distribution in the space where they are installed. In this case it was a typical scenario where the architect had placed them well hidden from view in a recessed void and behind angled louvers as shown in Fig. 07. The result is that instead of using the outside air temperature to reject the heat from the air-conditioners to, the units at the top of the building receive all the heat from the ones below increasing the temperature by 10+ °C, and on top of that the louvers trap the rejected heat causing another 10+ °C temperature rise. This reduces the performance of the machines well below the values that are expected for this Green Mark Platinum (BCA 2012) installation, labeled based on standard rated conditions, and it is a perfect example of a lack of understanding of the effect on the passive airflows caused by the active system leading to a drastic underperformance.

We have developed new design concepts, physically integrating active and passive elements. By integrating the ventilation ducting into the concrete slab while at the same time using hydronic piping to thermally activate the slab for cooling we can install the same cooling services into a space of around 30 cm that is often more than 2 m, as is the case for the Future Cities Laboratory office building at the campus of the National University of Singapore. The office building is very well designed in terms of energy performance, with high performance individual systems that meet the Green Mark Gold standard. But there is an enormous potential that can be realized if systems are considered together. In this case the structural elements of design can be integrated with the mechanical systems, eliminating the need for a plenum space, architecturally opening up the space for potentially higher ceilings, or allowing the construction of more floors in the same height. In the building we estimate that we could build 3 floors in the space of 2, thus spawning the designation we've given the concept: 342x.

We have embarked on an effort to increase the performance of cooling systems in the tropics using a LowEx design paradigm that we brought with us from Switzerland, along with proven technologies to test in this very different environment. What we have discovered goes beyond technologies themselves, and helps us to better understand the potential of integrated design. A common understanding of the linkages between passive and active systems and to the actual comfort expectations in building spaces can lead to spectacular gains in performance of design and operation.

Fig. 07 Kent Vale residential tower block where split unit location was studied

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