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Stuck in a stack—Temperature measurements of the microclimate around split type condensing units in a high rise building in Singapore☆

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ABSTRACT

The use of air-conditioning, the largest energy demand for buildings in the tropics, is increasing as regional population and affluence grow. The majority of installed systems are split type air-conditioners. While the performance of new equipment is much better, the influence of the microclimate where the condensing units are installed is often overlooked. Several studies have used CFD simulations to analyse the stack effect, a buoyancy-driven airflow induced by heat rejected from condensing units. This leads to higher on-coil temperatures, deteriorating the performance of the air-conditioners. We present the first field measurements from a 24-storey building in Singapore. A network of wireless temperature sensors measured the temperature around the stack of condensing units. We found that the temperatures in the void space increased continuously along the height of the building by 10–13 °C, showing a significant stack effect from the rejected heat from condensing units. We also found that hot air gets stuck behind louvres, built as aesthetic barriers, which increases the temperature another 9 °C. Temperatures of around 50 °C at the inlet of the condensing units for floors 10 and above are the combined result, reducing the unit efficiency by 32% compared to the undisturbed design case. This significant effect is completely neglected in building design and performance evaluation, and only with an integrated design process can truly efficient solutions be realised.

1. Introduction and background

While we researchers strive to increase energy efficiency and reduce greenhouse gas emissions from building operation, society continues to increases its expectation of the built environment. Just as European societies moved away from fireplaces and ovens as central heating technology became available, now developing countries expect more and more air conditioning. This is especially true in the rapidly growing market for individual split type or window type air-conditioning units, which ever more people are gaining access to in the developing world and large population centres in the tropics. If we are to address conglomerate growth of energy demand we must address the large-scale design and installation of these small system. The unchecked installation of split units has had a dramatic effect on façade aesthetic and form in places like Singapore, and the heat rejected by these systems is also largely unaddressed. We present for the first time experimental findings on the impact on local temperatures of the heat rejected from split units installed throughout a 24 story building in Singapore. Our results uncover a major influence on the temperatures adjacent to the building that will affect both comfort and the expected performance of the system, significantly lowering the efficiency of the air-conditioning equipment and degrading the comfort.

This reduced performance erodes away successes in increased efficiency in buildings, which must be broadly addressed because the energy used to create, operate and deconstruct buildings is a major anthropogenic contributor to greenhouse gas emissions and thus climate change. 76% of the total electricity consumption

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Fig. 1. Typical installation of split unit condensers in a crowded and hidden location.

in the US is used for buildings [1]. Due to their static nature and much untapped improvement potentials, buildings also represent a major opportunity for the reduction of further emissions. In the hot-humid tropics of Singapore, roughly 50% of the energy consumption in buildings is used for air-conditioning [2]. In 2007, 75% of all households were (partly) air-conditioned, a number that has certainly increased since [3]. Similar developments are expected in surrounding countries with increasing population and wealth.

By proxy there is evidence of the rise in the simple air conditioning solutions in the production of R-22, a refrigerant commonly used in small air-conditioners. It has been shown to be rapidly rising in developing countries [4]. This is a dangerous indicator for the further development of climate change, primarily in regard to the high global warming potential of R-22, but also as a significant indicator for the expanding installation of these types of small units. They are often sold as DIY units with a lack of professional installation that may address issues of proper spacing, setbacks from walls, and adequate air supply, all of which degrade an already limited performance. Even without the proxy data of R-22, it only takes a quick look around any of the rapidly growing cities in the tropics to realise the prevalence of these systems as shown clearly in Fig. 1.

In Singapore, one of the most developed of the cities in the tropics, efforts are being made to try to maximize the performance of such systems. One of the efforts, the Green Mark Scheme, a sustainable building certification scheme, was launched to promote sustainability in the built environment. They aim to have 80% of buildings Green Mark certified by 2030 [5], which will place a minimum efficiency on the installation of split units. Still the standard itself speaks to the inefficiency of these systems as buildings that use split units are rewarded with system efficiencies 33% lower than buildings with central chillers [6]. Green Mark certification only applies to whole building projects, but even at the consumer level Singapore has implemented a tick system to signify the quality of performance [7].

But all these efforts only address the purchased performance and are not related to the installed performance. The efficiency of air conditioning systems is directly related to the temperature at which it supplies cooling, and more importantly for these split units, the temperature at which it rejects the heat. The coefficient of performance (COP) is the ratio of the amount of cooling supplied to the electricity input into the cooling device. A typical chiller may have a COP of 3, delivering 3 kW of cooling for each 1 kW of electricity. But although this is often reported as a single value, it depends on the actual temperatures experienced by the system. Based on the LowEx building design paradigm [8] we focus on this temperature optimisation and recognize its significant influence on performance. This has led to the development of many new building systems in Switzerland [9,10], which can achieve better performance through a whole system evaluation that minimises temperature differences, allowing COPs higher than 10 [11].

Now we aim to achieve a similar optimisation for cooling systems in the tropics in our high temperature cooling system laboratory [12]. For split unit systems we must address the way in which they reject heat into the environment, because installation methods can significantly affect the temperature and therefore the actual performance. Finding the lowest possible temperature to reject the heat will deliver the highest performance, but we have evaluated the climate of Singapore, and there is little temperature variation that would provide better potential than the air as a heat sink [13]. Therefore it is essential to install the split unit systems in a way that take advantage of the coolest air temperature possible. Unfortunately standard practice overlooks the importance of this objective, and by looking at Fig. 1 it is clear how non-ideal higher temperatures may be generated around the units.

Few people enjoy the aesthetic of split type units hanging on façades as shown in Fig. 1. As a result they are often installed in spaces that are hidden from view, in recess spaces or in confined spaces such as inner light wells. Unfortunately, those spaces are often sheltered from wind to carry away the rejected heat. A *stack effect* is a possible consequence: The heat rejected from the condensing units induces a vertical, buoyancy-driven airflow, creating an increasingly hotter air bubble that rises up along the building. The condensing units further up have to reject heat to this hotter environment, and will thereby operate at reduced performance or, in extreme cases, may stop working if the working fluid cannot reach the necessary temperature any more.

A number of studies have been conducted, using CFD simulations to analyse the phenomenon, with Bojic reviewing the extensive CFD simulation studies on high-rise buildings in Hong Kong [14]. Chow argued that computer simulation was the most convenient and economical way to study the stack effect and found that the condenser on-coil temperatures rise more than 7 K for the top floors, for a high-rise residential building in Hong Kong [15]. In following studies, Chow and Bojic analysed the effect of the building re-entrant shape on the stack effect [16,17]. Bojic found the on-coil temperature increase by 4–9 K on the 30th storey, depending on the rejected heat per condensing unit (2–6 kW) [18]. Priyardarsini observed that the on-coil temperatures rise up to 38 °C for Singapore, when subject to wind flows perpendicular to a narrow urban canyon [19]. Choi analysed the situation where the condensing units are installed in an air-conditioning plant room. They found that the stack effect depended considerably on wind speed and wind direction. While moderate strength wind from the side lead to an increase of less than 2 K, frontal winds caused an increase of the on-coil temperature of 6 K over 40 storeys [20].

Chow [16] introduced the Condenser Group Performance Indicator (CGPI) that describes the average percentage drop in COP of a group of air-conditioners compared to the performance under a reference on-coil temperature T_{ref}. In that study, the performance drop was 9.4 to 25.5%, depending on wind and the shape of the re-entrant area where the condensing units were located. Choi [20] found values for CGPI between 5.07 and 22.25 for different wind speeds and direction.

What is missing are measured data that confirm, reject or alter the findings from the simulation studies. The only laboratory experiments we are aware of were conducted on a model in the scale 1:100, representing a 41-storey building, to measure the stack effect from water heaters in the inner light well [21]. While the aim was to study the natural ventilation characteristics for the removal of pollutants, it was used to test CFD models to study the stack effect from condensing units [22]. There are a variety of reasons that measured data from actual buildings is not available including the difficulty in setting up the measurements, the scale of the