Blog

UNIVERSITY COLLEGE LONDON

Unveiling Singapore's Power Predicament: Harnessing Natural Ventilation for a Sustainable Future

---

by

Chen Tian Lu

July, 2023

Nestled within the enchanting twilight hues of Singapore (Fig.1) lies a captivating cityscape that exudes charm and complexity. Yet, beneath its picturesque exterior lies an omnipresent challenge – the unyielding grip of heat. With the mercury oscillating between a nocturnal low of 23-25 °C and a scorching daytime high of 31-33 °C [1], Singapore is caught in the clutches of relentless warmth. As one's gaze wanders towards the distant skyline, where towering skyscrapers converge, an indomitable truth unveils itself – this metropolis boasts a staggering 100% urbanisation rate [2] and is home to 5.6 million people, making it the third most densely populated city on Earth [3]. It is within this confluence of circumstances that a pressing issue emerges: skyrocketing power consumption.

Figure 1. Views of Singapore

Electricity consumption has emerged as a formidable energy quandary in Singapore's ever-evolving landscape [1]. Harnessing historical data provided by the NEA and leveraging the power of machine learning algorithms, I conducted a forward-looking analysis to project the future trajectory of Singapore's electricity generation until 2030. The results, depicted in Figure 2, demonstrate an upward trajectory, indicating a continued surge in electricity generation based on the available data.

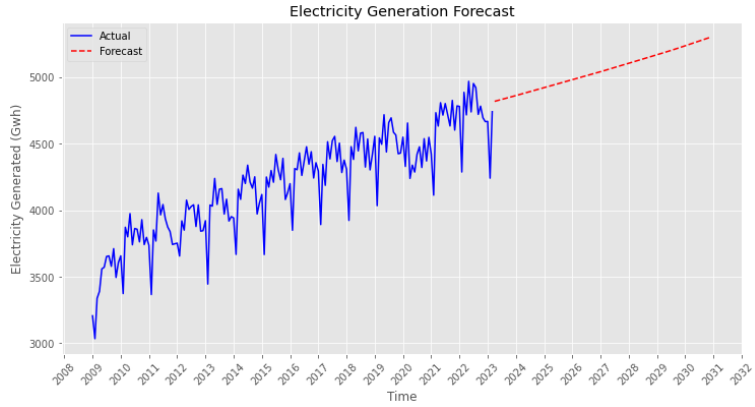


Figure 2. Singapore Power Generation Data History and Forecast

Recognising the electricity demand trend, the Singapore Government has embarked on a proactive quest to mitigate the escalating greenhouse gas emissions stemming from increased electricity consumption. With a steadfast focus on transforming the energy mix, the

government has prioritised a remarkable upswing in utilising natural gas – a clean and environmentally friendly energy source [4]. This strategic shift is impeccably illustrated in Figure 3.

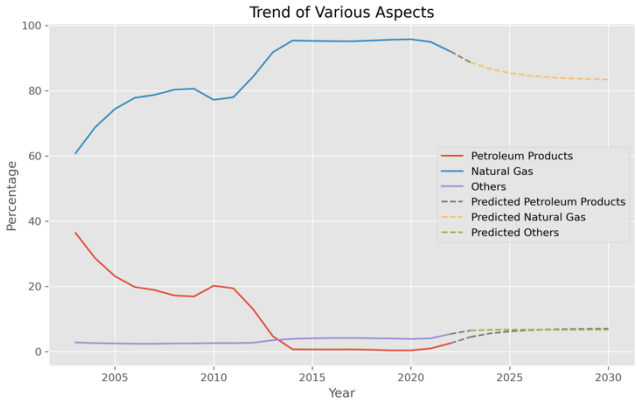


Figure 3. Singapore's Energy Mix and Projections

However, it is vital to acknowledge that while natural gas is deemed a "clean energy" source, its combustion process still emits substantial quantities of greenhouse gases, including carbon dioxide and methane [16]. This juxtaposition with sustainability objectives warrants a cautious approach. Notably, Figure 4 and Figure 5 elucidate that despite Singapore's commendable sustainability endeavours over the past two decades, there has been a limited decline in its Emission Factor. Furthermore, my neural network algorithm projections for Singapore's greenhouse gas emissions until 2030 indicate a continued upward trend.

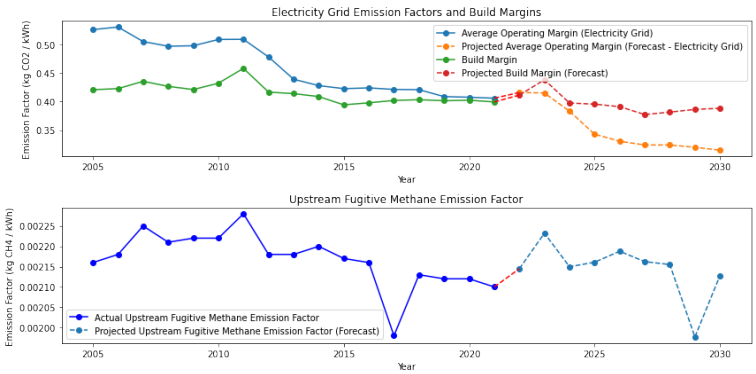


Figure 4. Emission Factors and Projections

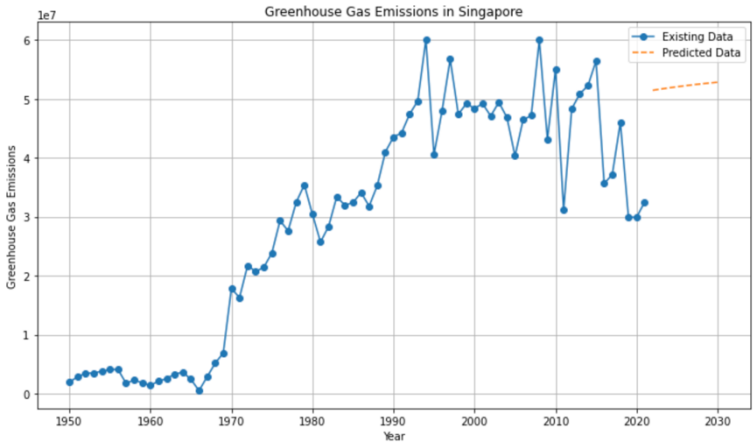


Figure 5. Emissions and Projections

In light of these observations, it becomes imperative for Singapore to identify the underlying factors contributing to its staggering electricity consumption. Resolving the energy conundrum necessitates a comprehensive understanding of the root causes and the implementation of practical solutions to curb this pressing issue.

Air conditioning systems have emerged as a dominant contributor to Singapore's electricity consumption, with buildings accounting for more than 50% of the total energy usage [1]. Within these buildings, air conditioning alone represents a significant proportion of the electricity consumed [1]. Compounding the challenge further, approximately 95% of Singapore's electricity is currently generated from imported natural gas sourced from Malaysia and Indonesia [6], posing concerns over energy security. From a sustainable energy development standpoint, Singapore faces a scarcity of alternative sources such as hydropower, geothermal, wind, tidal, and wave energy. Only solar power and biogas, harnessed through wired systems, offer a viable and stable renewable energy solution, albeit with limited availability.

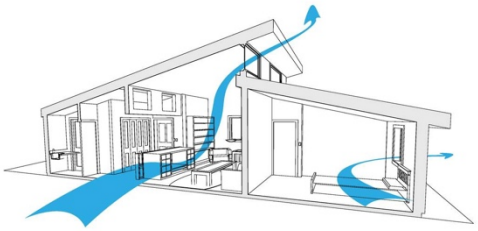
To address this pressing predicament, this article endeavours to tackle Singapore's electricity conundrum by honing in on reducing power consumption in air conditioning systems.

The pervasive dependence on air conditioning systems brings forth a host of drawbacks. Foremost, their extensive use contributes to the emission of greenhouse gases, exacerbating the challenges of climate change. Studies have revealed that even a marginal 1-degree Celsius rise in global temperatures correlates with a 3-4% surge in electricity consumption in Singapore, a phenomenon aptly known as Sick Building Syndrome (SRS) [1] [7]. Moreover, air-conditioned environments tend to exhibit elevated carbon dioxide levels compared to average bedrooms, leading to diminished occupant satisfaction [5].

People have been diligently investigating strategies for sustainable energy consumption in the architecture. Karecha et al. has proposed three sustainable building strategies [8], encompassing planning and design strategies, building envelope and material selection, and the incorporation of additional technologies. Natural ventilation stands as the foremost strategy among these, presenting itself as a fundamental approach toward achieving sustainable buildings.

In these sustainable strategies, natural ventilation as a zero-energy-consumption technique boasts numerous benefits. Most notably, it offers substantial energy savings for cooling, ranging from 10-30% annually [5] and even up to 55% in hot climates like Singapore's when combined with night ventilation [8]. Furthermore, natural ventilation significantly contributes to human health and well-being, as it leads to considerable reductions in carbon dioxide concentrations within naturally ventilated bedrooms, in contrast to their air-conditioned counterparts [5]. Consequently, this leads to higher levels of occupant satisfaction [6]. Moreover, natural ventilation enhances ventilation rates, thereby boosting human productivity and fostering a more serene ambience [9]. Lastly, embracing natural

ventilation brings economic benefits, including savings in air-conditioning mechanical system maintenance and operating costs [5], along with a notable reduction in accident rates.



By embracing the potential of natural ventilation, Singapore can embark on a transformative journey toward reducing the strain on its electricity grid, mitigating greenhouse gas emissions, and fostering a sustainable and healthier built environment.

Natural Ventilation

Thermal comfort:

When it comes to thermal comfort, the combination of high temperatures, humidity, and stagnant air can create an oppressive environment [10]. Singapore, with its tropical rainforest climate, is no stranger to such conditions. However, studies on thermal comfort have revealed that Singaporeans have adapted remarkably well, experiencing minimal discomfort in response to these climatic challenges [11]. Nevertheless, there remains a crucial need to enhance indoor air movement and maintain a more favourable temperature through effective ventilation strategies [12].

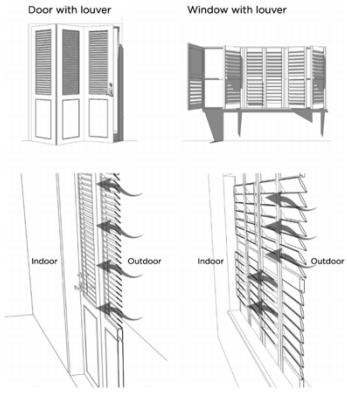


Figure 6. Shutter construction

Boosting indoor airflow can be achieved through a combination of internal and external measures. Internally, the installation of mechanical fans offers a cost-effective and energy-efficient alternative to air conditioning systems [1]. Additionally, adopting an active chimney strategy that incorporates chimney ventilation and extractor fans can significantly intensify indoor airflow by 40-60% [13]. Moreover, the installation of interior doors equipped with shutters, as depicted in Figure 6 [1] [5], proves to be an effective solution for improving room ventilation. By implementing these approaches, the intensity of indoor ventilation increases, allowing for a degree of thermal comfort to be achieved in buildings relying solely on natural ventilation.

Figure 7. Singapore Open Courtyard Architecture

On a larger scale, the overall impact of building design and layout on airflow strength for natural ventilation becomes crucial. In Singapore, the prevalent use of the open courtyard corridor design [1] in residential buildings and schools, as illustrated in Figure 7, enables the smooth passage of wind through open areas indicated by arrows. This design feature facilitates airflow within Singapore's densely populated urban landscape. Furthermore, the incorporation of ventilation corridors in urban planning has been an area where Singapore has excelled. As exemplified in Figure 8, Singapore's urban planning has dedicated ample space for ventilation corridors, laying a solid foundation for effective natural ventilation implementation. Another avenue for enhancing natural ventilation lies in retrofitting building facades, whereby the introduction of intelligent facades capable of reducing indoor temperatures by 2-3 degrees Celsius proves highly beneficial [3] [17] [18]. In summary, careful consideration of building layout, architectural design, and external devices can effectively lower indoor temperatures and enhance thermal comfort.

Figure 8. Singapore Urban Planning

By conscientiously considering and implementing these aspects of natural ventilation, Singapore can revolutionise its approach to energy consumption, alleviate the strain on the power grid, and create a more sustainable and comfortable living environment for its residents.

Natural Factors:

The effectiveness and quality of natural ventilation are influenced by external conditions and circumstances as outside air enters the room. Fortunately, Singapore benefits from excellent air quality, as showcased in Figure 9, which presents statistics and predictions based on historical air data. These data indicate that Singapore is projected to maintain over 98% good air quality throughout the year until 2030 [8]. This exceptional air quality not only allows natural ventilation to introduce fresh air but also contributes to the purification of indoor air. Consequently, what might be seen as a potential limitation becomes a positive aspect.

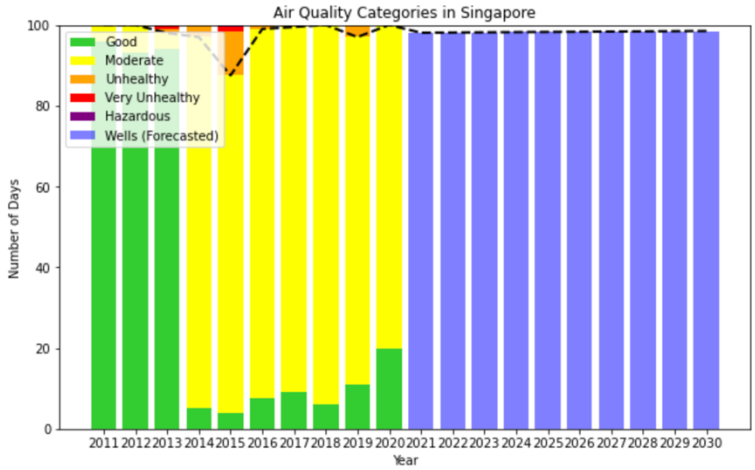


Figure 9. Singapore Air Quality and Forecast

In a city as rain-prone as Singapore, it is crucial to address the issue of rainwater leakage through natural ventilation openings. One practical solution is the installation of monsoon windows, which can be opened during windy and non-windy conditions, effectively mitigating rainwater leakage concerns during periods of rainfall [14] (Fig. 10).

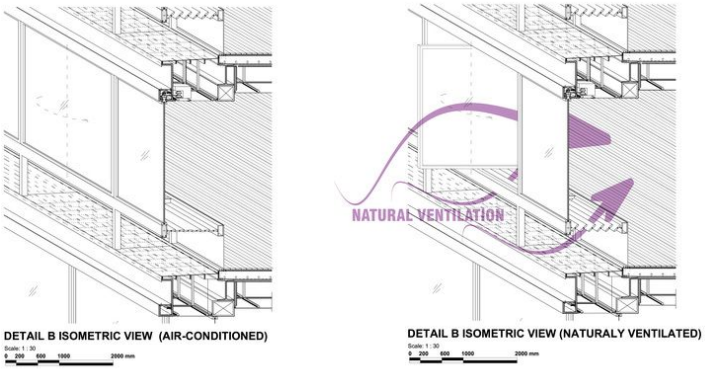


Figure 10. Monsoon Window Structure

To further enhance natural ventilation, a modelling analysis was conducted using linear regression under specific conditions:

1. Building power consumption accounts for approximately 50-60% of power generation.
2. Air conditioning contributes to around 50% of the building's power consumption.
3. The installation of natural ventilation can lead to a 25% reduction in air conditioning usage.
4. Natural ventilation installations were at 85% prior to the forecasting component, with an installation rate increasing by 30% per year during the forecasting phase.

The results are shown in Figure 11, whereby comparing the predicted curves for retrofitting natural ventilation (red dashed line) with those without retrofitting (green dashed line, purple dashed line showing an overall trend), there is a clear downward trend in power generation in Singapore, suggesting that natural ventilation is a very practical and effective option.

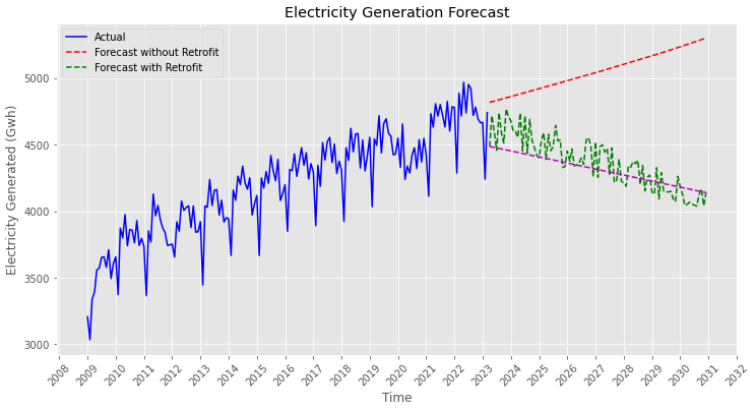


Figure 11. Power Generation Forecast after Natural Ventilation

However, not all challenges can be overcome solely through existing technologies. Acoustic pollution poses a significant concern in Singapore's bustling urban environment. Figure 12 highlights areas with high levels of noise pollution [15], emphasising the complexities natural ventilation solutions face. While natural ventilation introduces fresh air, it also allows outside noise into the room. This, in part, explains why Singapore continues to rely heavily on air conditioning systems despite the favourable conditions for natural ventilation [6]. Addressing the issue of acoustic pollution requires further research and innovation to find suitable and cost-effective solutions.

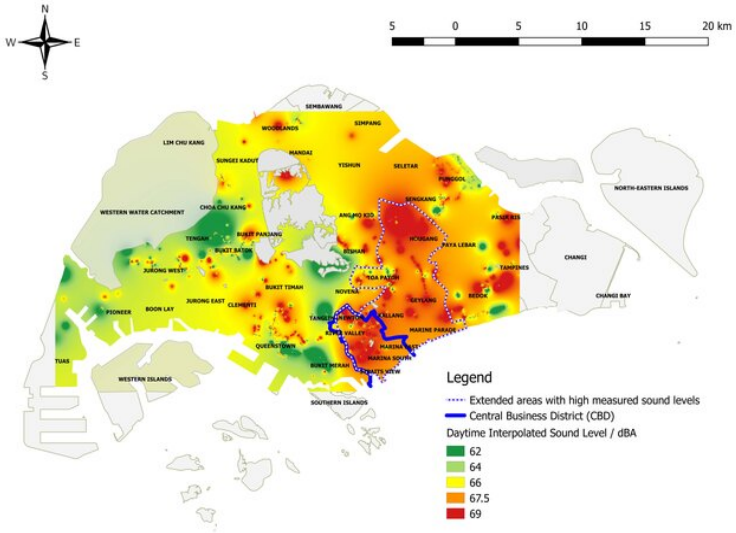


Figure 12. Singapore Acoustic Environment

In summary, using existing data and predictive modelling, Singapore's electricity consumption challenge has been analysed from various perspectives, including natural factors. The benefits of natural ventilation have been explored, leveraging the exceptional air quality in Singapore to its advantage. The potential of natural ventilation to reduce electricity consumption and its limitations, such as rainwater leakage and acoustic pollution, have been identified. By pursuing innovative approaches and further research, Singapore can harness the power of natural ventilation, contributing to reduced greenhouse gas emissions and a more sustainable future.

References

[1] N. H. Wong, E. Tanand A. S. Adelia, "Utilization of Natural Ventilation for Hot and Humid Singapore", 2020, pp. 165–184. doi: 10.1007/978-981-13-7519-4_8.

[2] Population and Population Structure (2017) Department of Statistics Singapore.https://www.singstat.gov.sg/find-data/search-by-theme/population/population-and-population-structure/latest-data. Accessed 23 July 2018

[3] Population Density (people per sg. km of land area) (2018) World Bank Group.http://databank.worldbank.org/data/reports.aspx?source=2&series=EN.POP.DNST&country=.Accessed 16 Aug 2018

[4] K. A. Al-Sallal and A. R. Abouelhamd, "Natural Ventilation in Hot Seaside Urban Environments", in Innovative Renewable Energy, Innovative Renewable Energy, 2018, pp. 27–41. doi: 10.1007/978-3-319-67949-5_3.

[5] Wong NH (2002) Natural ventilation studies of public housing in Singapore. Research project report, National University of Singapore

[6] Santamouris, M., & Asimakopoulos, D. (1987). Passive cooling of buildings. London: James and James Science.

[7] Hummelgaard J, Juhl P, Sæbjörnsson KO, Clausen G, Toftum J, Langkilde G (2007) Indoor air quality and occupant satisfaction in five mechanically and four naturally ventilated open-plan office buildings. Build Environ 42(12):4051–4058. https://doi.org/10.1016/j.buildenv.2006.07.042

[8] Santamouris M, Wouters P (2006) Building ventilation: the state of art. Earthscan, London, Sterling, Va

[9] Wong NH (2008) Tropical urban heat islands: climate, buildings, and greenery, 1st edn. Taylor & Francis, New York

[10] Givoni B, Khedari J, Wong NH, Feriadi H, Noguchi M (2006) Thermal sensation responses in hot, humid climates: effects of humidity. Build Res Inf 34(5):496–506. https://doi.org/10.1080/09613210600861269

[11] Wong NH, Feriadi H, Lim PY, Tham KW, Sekhar C, Cheong KW (2002) Thermal comfort evaluation of naturally ventilated public housing in singapore. Build Environ 37(12):1267–1277. https://doi.org/10.1016/S0360-1323(01)00103-2

[12] Santamouris, M. (2005). Energy in the urban built environment: The role of natural

ventilation. Natural ventilation in the urban environment: Assessment and design, 1–19.

[13] Nyuk Hien Wong, Sani Heryanto. (2004) The study of active stack effect to enhance natural ventilation using wind tunnel and computational fluid dynamics (CFD) simulations. Energy and Buildings 36:7, pages 668-678.

[14] Neha Gupta, Pooja Rani, G. N. Tiwari. (2022) Effect of movable insulation on performance of the Building integrated Semi-transparent Photovoltaic Thermal (BiSPVT) system for harsh cold climatic conditions: a case study. International Journal of Ambient Energy 43:1, pages 4224-4238.

[15] Johnston P, Ainley R, Aga Khan Award for Architecture (Organization) (2007) Intervention architecture: building for change. London: I.B. Tauris & Co Ltd

[16] K. A. Johnson , D. E. Johnson, Methane emissions from cattle, Journal of Animal Science, Volume 73, Issue 8, August 1995, Pages 2483–2492, https://doi.org/10.2527/1995.7382483x

[17] F. Flourentzou, S. Pantet, K. Ritz, "Design and performance of controlled natural ventilation in school gymnasiums" , International Journal of Environmental Science and Development, Vol. 6, No. 2, pp.2044-4044, 2015. Available: https://www.tandfonline.com/loi/tjov20

[18] E. Souza, "Natural Ventilation Isn't the Most Efficient Solution in All Cases" [Online]. Available: https://www.archdaily.com/958430/natural-ventilation-isnt-the-most-efficient-solution-in-all-cases?ad_source=search&ad_medium=search_result_articles [Accessed Apr.15, 2021]