

BAB VI

KESIMPULAN

6.1 Simpulan

Berdasarkan hasil simulasi dan analisis yang telah dilakukan, simpulan utama penelitian ini dapat dirumuskan sebagai berikut.:

1. Penerapan modul solusi individu (*single* TWC) belum mampu memenuhi kriteria performa ventilasi alami secara menyeluruh

Penerapan Single Tower Windcatcher (TWC) terbukti tidak memadai untuk bangunan 10 lantai tanpa void. Hasil simulasi menunjukkan kecepatan udara rata-rata di zona hunian interior hanya berkisar 0 - 0,2 m/s, yang mengindikasikan kondisi stagnasi udara ($ACH < \text{standar}$) akibat ketiadaan mekanisme perbedaan tekanan (*pressure loop*) yang efektif.

2. Kombinasi TWC-SC secara signifikan meningkatkan kinerja ventilasi alami

Integrasi TWC-SC terbukti secara signifikan meningkatkan kinerja ventilasi. Pada zona paling optimal (Lantai 10), tercatat peningkatan kecepatan udara hingga 0,7 m/s dan lonjakan nilai *Air Change per Hour* (ACH) mencapai 44,12 kali/jam, jauh melampaui standar minimum ventilasi alami.

3. Karakteristik performa ventilasi menunjukkan perbedaan yang jelas antar ketinggian lantai

Lantai 1 (Zona Bawah): Mengalami kendala kecepatan aliran ($\pm 0,15$ m/s) akibat hambatan *wake* bangunan sekitar, meskipun suhu relatif lebih rendah. Lantai 5 (Zona Tengah): Mengalami peningkatan ACH signifikan (21,49 ACH) , namun kenyamanan termal terganggu oleh akumulasi panas (*heat trapping*) dengan

temperatur operatif mencapai 29-32°C. Sementara itu, Lantai 10 (Zona Atas): Mencapai performa terbaik dengan keseimbangan antara kecepatan angin tinggi (5,8 m/s) dan mekanisme stack effect maksimal.

4. Interaksi *wind-driven ventilation* dan *stack effect* bersifat saling melengkapi, bukan substitutif

interaksi antara *wind-driven ventilation* dan *stack effect* bersifat saling melengkapi, bukan substitutif. Hasil penelitian ini menunjukkan bahwa ventilasi alami pada bangunan tinggi tanpa void tidak dapat dipahami hanya sebagai hubungan linier antara inlet dan outlet. Ruang dalam bangunan berperan aktif dalam membentuk pola aliran melalui redistribusi tekanan, peredaman turbulensi, serta pembentukan lapisan aliran yang berkaitan dengan ketinggian aktivitas manusia. Integrasi TWC dan SC memungkinkan mekanisme tekanan angin dan gaya apung termal bekerja secara simultan dan adaptif terhadap variasi kondisi lingkungan.

5. Nilai ACH yang dihasilkan sistem TWC-SC menunjukkan potensi pengurangan ketergantungan pada ventilasi mekanis

Nilai ACH pada skenario kombinasi TWC-SC menunjukkan potensi yang jelas dalam mengurangi ketergantungan pada ventilasi mekanis. Meskipun belum seluruh zona mencapai kondisi ideal, peningkatan ACH yang konsisten menegaskan bahwa strategi ini layak diterapkan sebagai solusi ventilasi pasif pada gedung perkantoran bertingkat di iklim tropis lembap. Temuan ini sekaligus memperluas pemahaman ventilasi alami sebagai sistem spasial tiga dimensi yang dipengaruhi oleh geometri bangunan, ketinggian lantai, dan mekanisme fisika aliran udara.

6. Paradoks Kenyamanan

Terdapat diskrepansi antara performa aerodinamis dan kenyamanan termal. Meskipun ACH sangat tinggi (memenuhi SNI), kenyamanan termal adaptif pada skenario kelembapan tinggi ($RH > 85\%$) sulit dicapai hanya dengan kecepatan angin, itu mengonfirmasi bahwa di iklim tropis lembap, kontrol kelembapan sama krusialnya dengan kecepatan udara.

6.2 Rekomendasi

Berdasarkan hasil penelitian dan keterbatasan yang ditemui, maka rekomendasi yang dapat disampaikan adalah sebagai berikut:

1. Rekomendasi desain
 - a. Sistem TWC-SC harus dirancang terintegrasi sejak awal massing. Disarankan menggunakan rasio inlet-outlet 2:4 (sesuai temuan penelitian) untuk memastikan gaya hisap *buoyancy* cukup kuat melawan hambatan gesek pada bangunan tinggi.
 - b. Penggunaan *Stepped Solar Chimney* sangat direkomendasikan untuk bangunan tanpa void guna mencegah reverse flow dan memastikan distribusi tekanan yang merata di lantai tengah, yang sering menjadi zona mati ventilasi.
 - c. Desain interior perlu mempertimbangkan jalur aliran udara horizontal agar distribusi ventilasi tidak terhambat oleh sekat atau tata ruang yang terlalu padat.

- d. Mengingat masalah kelembapan tinggi, disarankan integrasi material higroskopis (*desiccant*) pada dinding interior atau sistem ventilasi hibrida (mekanis-alami) yang aktif hanya saat $RH > 80\%$.
2. Rekomendasi implementasi praktis
 - a. Sistem TWC-SC dapat diimplementasikan sebagai strategi *hybrid passive ventilation* pada gedung perkantoran pemerintah untuk menurunkan konsumsi energi operasional, khususnya beban pendinginan.
 - b. Penerapan sistem ini perlu disertai dengan pengaturan operasional adaptif, misalnya integrasi dengan kontrol bukaan atau sistem monitoring berbasis sensor untuk menyesuaikan kinerja ventilasi terhadap kondisi iklim harian.
 - c. Implementasi pada bangunan eksisting sebaiknya dilakukan melalui pendekatan retrofit bertahap, terutama pada bangunan yang tidak memungkinkan penambahan void internal.
 3. Rekomendasi Penelitian Selanjutnya
 - a. Penelitian ini menggunakan simulasi *steady-state* pada pukul 10.00 WIB. Penelitian selanjutnya disarankan menggunakan simulasi Transient (*Unsteady*) selama siklus 24 jam untuk menangkap fenomena thermal lag (pelepasan panas lambat) material beton pada malam hari.
 - b. Validasi eksperimental menggunakan uji terowongan angin (*wind tunnel*) atau pengukuran lapangan skala penuh (*full-scale measurement*) sangat

diperlukan untuk mengkalibrasi model turbulensi RANS yang digunakan dalam simulasi ini.



DAFTAR PUSTAKA

- Aflaki, A., Mahyuddin, N., Mahmoud, Z.A.-C., Baharum, M.R., 2015. A review on natural ventilation applications through building façade components and ventilation openings in tropical climates. *Energy Build.* 101, 153-162.
- Alhraki, A.R., Sultan Qurraie, B., 2025. CFD evaluation of wind catcher geometry and internal partitions for enhanced ventilation in Nizwa, Oman. *J. Innov. Eng. Nat. Sci.* 5, 55-69. <https://doi.org/10.61112/jiens.1496075>
- Allard, F., Santamouris, M., 1998. Natural ventilation in buildings-a design handbook.
- Allocca, C., Taylor, S., Mead, S., 2003. Designing for natural ventilation: Criteria and constraints. *Energy Build.* 35, 229-237. [https://doi.org/10.1016/S0378-7788\(02\)00136-2](https://doi.org/10.1016/S0378-7788(02)00136-2)
- Almazmumi, S., Owen, J., Jimenez-bescos, C., Calautit, J.K., 2025a. Numerical modeling and wind tunnel testing of a novel wall windcatcher natural ventilation system for multi-floor buildings. *Energy Build.* 349, 116427. <https://doi.org/10.1016/J.ENBUILD.2025.116427>
- Almazmumi, S., Owen, J.S., Jimenez-Bescos, C., Calautit, J.K., 2025b. Numerical modeling and wind tunnel testing of a novel wall windcatcher natural ventilation system for multi-floor buildings. *Energy Build.* 349, 116427. <https://doi.org/10.1016/J.ENBUILD.2025.116427>
- Almazmumi, S., Sun, H., Liu, M., Calautit, J., Jimenez-bescos, C., 2025c. A novel wall windcatcher (WWC) natural ventilation system evaluated through CFD and experimental field testing - a solution to single-sided ventilation in multi-story buildings? *Build. Environ.* 283, 113307. <https://doi.org/10.1016/j.buildenv.2025.113307>
- Alsailani, M., Montazeri, H., Rezaeiha, A., 2021a. Towards optimal aerodynamic design of wind catchers: Impact of geometrical characteristics. *Renew. Energy* 168, 1344-1363.
- Alsailani, M., Montazeri, H., Rezaeiha, A., 2021b. Towards optimal aerodynamic design of wind catchers: Impact of geometrical characteristics. *Renew. Energy* 168, 1344-1363. <https://doi.org/10.1016/j.renene.2020.12.053>
- Arumugam, J., MP, M., SM, S.N., 2024. Subjective evaluation of thermal comfort of tropically acclimatized subjects in air conditioned, naturally ventilated and radiant cooling environments. *Build. Serv. Eng. Res. Technol.* 45, 655-681.

- Asfour, O.S., 2015. Natural ventilation in buildings: An overview. Nova Science Publishers, Inc.
- Autodesk, 2023. How to determine the time scale of a steady state in Autodesk CFD [WWW Document]. URL <https://www.autodesk.com/support/technical/article/caas/sfdcarticles/sfdcarticles/How-to-determine-the-time-scale-of-a-steady-state-CFD-simulation.html> (accessed 10.16.25).
- Autodesk, 2015. Autodesk Simulation CFD External Flow Validation: NACA 0012 Airfoil. Rev. NACA0012 2D 14.
- Awbi, H.B., 2003. Ventilation of Buildings. Spon Press.
- Azmi, N.A., Baharun, A., Arıcı, M., Ibrahim, S.H., 2023. Improving thermal comfort in mosques of hot-humid climates through passive and low-energy design strategies. *Front. Archit. Res.* 12, 361-385.
- Balabel, A., Faizan, M., Alzaed, A., 2021. Towards a Computational Fluid Dynamics-Based Fuzzy Logic Controller of the Optimum Windcatcher Internal Design for Efficient Natural Ventilation in Buildings 2021. <https://doi.org/10.1155/2021/9936178>
- Benkari, N., Fazil, I., Husain, A., 2017. Design and performance comparison of two patterns of wind-catcher for a semi-enclosed courtyard. *Int. J. Mech. Eng. Robot. Res.* 6, 396-400.
- Blocken, B., Stathopoulos, T., Carmeliet, J., 2008. Wind environmental conditions in passages between two long narrow perpendicular buildings. *J. Aerosp. Eng.* 21, 280-287.
- Blocken, B., Stathopoulos, T., Carmeliet, J., Hensen, J., 2009. Application of CFD in building performance simulation for the outdoor environment, in: *Building Simulation 2009*. IBPSA, pp. 489-496.
- BSN, 2001. Tata Cara Perancangan Sistem Ventilasi dan Pengkondisian Udara pada Bangunan Gedung. Sni 03-6572-2001 1-55.
- Buonocore, C., De Vecchi, R., Scalco, V., Lamberts, R., 2018. Influence of relative air humidity and movement on human thermal perception in classrooms in a hot and humid climate. *Build. Environ.* 146, 98-106.
- Cai, W., Wu, Z., Wang, H., 2011. Effect of ventilation and air conditioning system on indoor air quality of low-carbon buildings, in: *2011 International Conference on Electric Technology and Civil Engineering (ICETCE)*. IEEE, pp. 3118-3121.

- Cen, C., Cheng, S., Wong, N.H., 2023. Effect of elevated air temperature and air velocity on thermal comfort and cognitive performance in the tropics. *Build. Environ.* 234, 110203.
- Che, W.W., Tso, C.Y., Sun, L., Ip, D.Y.K., Lee, H., Chao, C.Y.H., Lau, A.K.H., 2019. Energy consumption, indoor thermal comfort and air quality in a commercial office with retrofitted heat, ventilation and air conditioning (HVAC) system. *Energy Build.* 201, 202-215. <https://doi.org/10.1016/j.enbuild.2019.06.029>
- CIBSE, 2005. Guide A: Environmental Design. Chartered Institution of Building Services Engineers.
- Darmawan, S., Tanujaya, H., 2019. CFD investigation of flow over a backward-facing step using an RNG k- ϵ turbulence model. *Int. J. Technol.* 10, 280-289. <https://doi.org/10.14716/ijtech.v10i2.800>
- ESDM, K., 2020. Handbook of Energy & Economic Statistics of Indonesia 2020.
- Etheridge, D., 2011. Natural Ventilation of Buildings: Theory, Measurement and Design. Wiley.
- Fang, Z., Wang, W., Chen, Y., Song, J., 2022. Structural and Heat Transfer Model Analysis of Wall-Mounted Solar Chimney Inlets and Outlets in Single-Story Buildings.
- Fanger, P.O., 1970. Thermal comfort. Analysis and applications in environmental engineering.
- Fereidoni, S., Fereidooni, L., Tamjid, S., Sadegh, M., Zare, M., Kasaeian, A., 2025. Application of solar chimneys and hybrid solar chimneys for ventilation in buildings: A review. *Sol. Energy* 288, 113246. <https://doi.org/10.1016/j.solener.2025.113246>
- GanGuohui, 2010. Interaction Between Wind and Buoyancy Effects in Natural Ventilation of Buildings. *Open Constr. Build. Technol. J.* <https://doi.org/10.2174/1874836801004010134>
- Glumac, A.Š., Hemida, H., Höffer, R., 2018. Wind energy potential above a high-rise building influenced by neighboring buildings: An experimental investigation. *J. Wind Eng. Ind. Aerodyn.* 175, 32-42.
- Gong, J., Chew, L.W., Lee, P.S., 2023. Shape optimization of high-rise solar chimneys to improve the uniformity of flowrate distribution. *Build. Environ.* 243, 110650. <https://doi.org/10.1016/j.buildenv.2023.110650>
- Handbook, A.R.R., 2005. ASHRAE handbook fundamentals.

- He, G., Wu, Q., Li, Z., Ge, W., Lv, D., Cong, L., 2021. Ventilation performance of solar chimney in a test house: Field measurement and validation of plume model. *Build. Environ.* 193, 107648.
- Heidari, A.A., Eskandari, H., 2022. Impact of inlet and outlet opening height variation on the air quality and ventilation efficiency in the on-top wind catcher buildings: A CFD simulation. *Sci. Technol. Built Environ.* 28, 1420-1438.
- Holford, J.M., Hunt, G.R., 2003. Fundamental atrium design for natural ventilation. *Build. Environ.* 38, 409-426. [https://doi.org/10.1016/S0360-1323\(02\)00019-7](https://doi.org/10.1016/S0360-1323(02)00019-7)
- Ibrahim, M., Abdelhady, M., 2023. Computational Investigation for The Windcatcher Top Roof Length Effect on Indoor Air Quality - simulation study 145-160. <https://doi.org/10.21608/MJAF.2021.80674.2367>
- Iskandar, L., Bay-Sahin, E., Martinez-Molina, A., Toker Beeson, S., 2024. Evaluation of passive cooling through natural ventilation strategies in historic residential buildings using CFD simulations. *Energy Build.* 308, 114005. <https://doi.org/10.1016/j.enbuild.2024.114005>
- Jesson, M., Sterling, M., Letchford, C., Baker, C., 2015. Aerodynamic forces on the roofs of low-, mid- and high-rise buildings subject to transient winds. *J. Wind Eng. Ind. Aerodyn.* 143, 42-49. <https://doi.org/10.1016/j.jweia.2015.04.020>
- Kubota, T., Kumar, N., Kitagawa, H., Maeda, T., Asawa, T., 2023. Effects of Vertical Void on Natural Ventilation in Double-Loaded Apartments. *AIJ Annu. Conf.* 2, 833-834.
- Kumar, D., Kumar, K., Biswas, N., Manna, N.K., 2025. Optimization of hybrid solar chimney power plants (HSCPPs): A review of multi-objective approaches. *Appl. Energy* 396, 126214. <https://doi.org/10.1016/j.apenergy.2025.126214>
- Kumar, N., Kubota, T., Tominaga, Y., Shirzadi, M., Bardhan, R., 2021. CFD simulations of wind-induced ventilation in apartment buildings with vertical voids: Effects of pilotis and wind fin on ventilation performance. *Build. Environ.* 194, 107666. <https://doi.org/10.1016/j.buildenv.2021.107666>
- Lee, K.Y., Mak, C.M., 2021. Effects of wind direction and building array arrangement on airflow and contaminant distributions in the central space of buildings. *Build. Environ.* 205, 108234.
- Li, J., Calautit, J., Jimenez-bescos, C., Riffat, S., 2023. Experimental and numerical evaluation of a novel dual-channel windcatcher with a rotary scoop for energy-saving technology integration. *Build. Environ.* 230, 110018. <https://doi.org/10.1016/j.buildenv.2023.110018>

- Li, J., Calautit, J., Jimenez-Bescos, C., Song, W., Riffat, S., Chen, Q., 2025. Climate-adaptive windcatcher natural ventilation integrated with passive and low-energy technologies: A review of current and future developments. *Build. Environ.* 284. <https://doi.org/10.1016/j.buildenv.2025.113436>
- Li, L., Mak, C.M., 2007. The assessment of the performance of a windcatcher system using computational fluid dynamics 42, 1135-1141. <https://doi.org/10.1016/j.buildenv.2005.12.015>
- Liddament, M.W., 1996. *A Guide to Energy Efficient Ventilation*.
- Lin, P., Qin, H., Lau, S.S.Y., Wei, Q., 2025. Impact of unit type and configuration on indoor natural ventilation performance of high-rise, high-density residential buildings in Hong Kong. *Build. Environ.* 269, 112444. <https://doi.org/10.1016/j.buildenv.2024.112444>
- Linden, P.F., 1999. The fluid mechanics of natural ventilation. *Annu. Rev. Fluid Mech.* 31, 201-238.
- Liu, M., Nejat, P., Cao, P., Jimenez-Bescos, C., Calautit, J.K., 2024a. A critical review of windcatcher ventilation: Micro-environment, techno-economics, and commercialisation. *Renew. Sustain. Energy Rev.* 191, 114048. <https://doi.org/10.1016/j.rser.2023.114048>
- Liu, M., Nejat, P., Cao, P., Jimenez-Bescos, C., Calautit, J.K., 2024b. A critical review of windcatcher ventilation: Micro-environment, techno-economics, and commercialisation. *Renew. Sustain. Energy Rev.* 191, 114048. <https://doi.org/10.1016/J.RSER.2023.114048>
- Liu, X., Wang, H., Li, Z., Zhao, J., Li, C., Xie, D., 2024. Effectiveness of natural ventilation through single-sided window opening in air-conditioning rooms. *Energy Build.* 314, 114260. <https://doi.org/10.1016/j.enbuild.2024.114260>
- López Plazas, F., Sáenz de Tejada, C., 2024. Natural ventilation to improve indoor air quality (IAQ) in existing homes: The development of health-based and context-specific user guidelines. *Energy Build.* 314. <https://doi.org/10.1016/j.enbuild.2024.114248>
- Lu, Y., Dong, J., Wang, Z., Wang, Y., Wu, Q., Wang, L., Liu, J., 2021. Evaluation of stack ventilation in a large space using zonal simulation and a reduced-scale model experiment with particle image velocimetry. *J. Build. Eng.* 34, 101958. <https://doi.org/10.1016/j.job.2020.101958>
- Maghrabie, H.M., Abdelkareem, M.A., Elsaid, K., Sayed, E.T., Radwan, A., Rezk, H., Wilberforce, T., Abo-Khalil, A.G., Olabi, A.G., 2022a. A review of solar chimney for natural ventilation of residential and non-residential buildings. *Sustain. Energy Technol. Assessments* 52, 102082.

- Maghrabie, H.M., Ali, M., Elsaid, K., Taha, E., Radwan, A., Rezk, H., Wilberforce, T., Abo-khalil, A.G., Olabi, A.G., 2022b. A review of solar chimney for natural ventilation of residential and non-residential buildings. *Sustain. Energy Technol. Assessments* 52, 102082. <https://doi.org/10.1016/j.seta.2022.102082>
- Mamari, M. Al, Khan, H.M., Al Saadi, S., Al Hashim, A., 2025. Impact of windcatcher on the thermal comfort and indoor air quality in a modern house. *Build. Res. Inf.* 53, 204-219. <https://doi.org/10.1080/09613218.2024.2386580>
- Mao, J., Gao, N., 2015. The airborne transmission of infection between flats in high-rise residential buildings: A review. *Build. Environ.* 94, 516-531. <https://doi.org/10.1016/j.buildenv.2015.09.026>
- Mayhoub, M., Selim, H., Abuzaid, A., 2025. Roadmap to developing a geometrical design guide for windcatchers. *Front. Built Environ.* 11. <https://doi.org/10.3389/fbuil.2025.1534284>
- Moey, L.K., Sing, Y.H., Tai, V.C., Go, T.F., Ng, J.Y., 2022. Numerical investigation of inlet opening size on wind-driven cross ventilation. *J. Mech. Eng. Sci.* 16, 8662-8672. <https://doi.org/10.15282/jmes.16.1.2022.02.0685>
- Montazeri, H., 2011a. Experimental and numerical study on natural ventilation performance of various multi-opening wind catchers. *Build. Environ.* 46, 370-378. <https://doi.org/10.1016/j.buildenv.2010.07.031>
- Montazeri, H., 2011b. Experimental and numerical study on natural ventilation performance of various multi-opening wind catchers. *Build. Environ.* 46, 370-378.
- Montazeri, H., Montazeri, F., 2018. CFD simulation of cross-ventilation in buildings using rooftop wind-catchers: Impact of outlet openings. *Renew. Energy* 118, 502-520.
- Moore, G.A., 2011. *Escape Velocity: Free Your Company's Future from the Pull of the Past*. Harper Collins.
- Moosavi, L., Zandi, M., Bidi, M., Behroozizade, E., Kazemi, I., 2020. New design for solar chimney with integrated windcatcher for space cooling and ventilation. *Build. Environ.* 181, 106785. <https://doi.org/10.1016/j.buildenv.2020.106785>
- Najafi, N., Cook, M.J., Freidooni, F., Sullivan, P.D.O., 2023. The role of near-façade flow in wind-dominant single-sided natural ventilation for an isolated three-storey building: An LES study. *Build. Environ.* 235, 110210. <https://doi.org/10.1016/j.buildenv.2023.110210>

- Najafi Ziarani, N., Cook, M.J., O'Sullivan, P.D., 2023. Experimental evaluation of airflow guiding components for wind-driven single-sided natural ventilation: A comparative study in a test chamber. *Energy Build.* 300, 113627. <https://doi.org/10.1016/J.ENBUILD.2023.113627>
- Nejat, P., Fekri, Y., Pourghasemian, M.H., Alsaad, H., Voelker, C., 2025a. Passive cooling assessment of natural ventilation by windcatchers for enhancing thermal comfort and indoor air quality in European schools. *Build. Environ.* 276, 112848.
- Nejat, P., Fekri, Y., Pourghasemian, M.H., Alsaad, H., Voelker, C., 2025b. Passive cooling assessment of natural ventilation by windcatchers for enhancing thermal comfort and indoor air quality in European schools. *Build. Environ.* 276, 112848. <https://doi.org/10.1016/J.BUILDENV.2025.112848>
- Nguyen, Y.Q., Nguyen, V.T., 2023. Characterizing the induced flow through the cavity of a wall solar chimney under the effects of the opening heights. *J. Build. Phys.* 46, 630-653.
- Nikdash, A., Huynh, B.P., 2016. ICCM2015: A Comparison of RANS and LES Computational Methods in Analyzing Ventilation Flow Through a Room Fitted with a Two-Sided Windcatcher. *Int. J. Comput. Methods* 14, 1750021. <https://doi.org/10.1142/S0219876217500219>
- Nouh Ma'bdeh, S., Fawwaz Alrebei, O., Obeidat, L.M., Al-Radaideh, T., Kaouri, K., Amhamed, A.I., 2023. Quantifying energy reduction and thermal comfort for a residential building ventilated with a window-windcatcher: A case study. *Buildings* 13, 86.
- Pardo-del Viejo, L., Fernández-Rodríguez, S., 2024. CFD with LIDAR applied to buildings and vegetation for environmental construction. *Autom. Constr.* 167, 105710.
- Pardo-del Viejo, L., Fernández-Rodríguez, S., 2024. CFD with LIDAR applied to buildings and vegetation for environmental construction. *Autom. Constr.* 167, 105710. <https://doi.org/10.1016/J.AUTCON.2024.105710>
- Prajongsan, P., Sharples, S., 2012. Enhancing natural ventilation, thermal comfort and energy savings in high-rise residential buildings in Bangkok through the use of ventilation shafts. *Build. Environ.* 50, 104-113.
- Prihatanti, N.A., Ekasiwi, S.N.N., Defiana, I., 2021. Effects of Pivot Windows and Wing Walls on Single Sided Natural Ventilation in Rumah Susun (Walk Up Flat). *IPTEK J. Proc. Ser.* 0, 411. <https://doi.org/10.12962/j23546026.y2020i6.11132>

- Prima, Y., Prima, S., 2019. Wind catcher and solar chimney integrated as an alternative ventilation for urban dense settlements in tropical climate. *Int. J. Archit. Urban.* 3, 51-68.
- Prima, Y., Sugini, 2019. Wind catcher and solar chimney integrated as an alternative ventilation for urban dense settlements in tropical climate. *Int. J. Archit. Urban.* 3, 51-68.
- Qadourah, J.A., 2024. Improving Natural Ventilation Multi-Story Buildings within Hot and Dry Climates: A CFD Study of Windcatcher Performance. *Civ. Eng. Archit.* 12, 1014-1026. <https://doi.org/10.13189/cea.2024.120225>
- Ramadhan, A., 2024. Perubahan Bentuk Dan Fungsi Alun-Alun Bandung. *Desa - Des. Archit. J.* 4, 58-68. <https://doi.org/10.34010/desa.v4i2.14387>
- Rateb, A., 2025. CFD evaluation of wind catcher geometry and internal partitions for enhanced ventilation in Nizwa 5, 55-69.
- Sangdeh, P.K., Nasrollahi, N., 2022. Windcatchers and their applications in contemporary architecture. *Energy Built Environ.* 3, 56-72. <https://doi.org/10.1016/j.enbenv.2020.10.005>
- Serra, N., 2023. Revisiting RANS turbulence modelling used in built-environment CFD simulations. *Build. Environ.* 237, 110333. <https://doi.org/10.1016/J.BUILDENV.2023.110333>
- Shi, X., Li, Y., Long, T., Zhao, N., Liu, S., Li, T., 2023. Buoyancy-driven natural ventilation performance of a multi-story building with vertical shaft designed by using dimensionless design approach. *Sustain. Cities Soc.* 99, 104997. <https://doi.org/10.1016/j.scs.2023.104997>
- Simularge, 2024. Steady-State vs. Transient Modeling in CFD: Choosing the Right Approach [WWW Document]. Simularge. URL <https://www.simularge.com/blog/steady-state-vs-transient-modeling-in-cfd-choosing-the-right-approach> (accessed 10.16.25).
- Sornek, K., Figaj, R., Papis-fr, K., 2025. Development and tests of the novel configuration of the solar chimney with sensible heat storage 258. <https://doi.org/10.1016/j.applthermaleng.2024.124515>
- Tantasavasdi, C., Arttamart, S., Inprom, N., 2025. Combined wind catchers and side windows for cross ventilation in row houses. *J. Eng. Des. Technol.* 23, 1039-1056.
- Teng, X., Oo, M.L., Ge, J., Wong, N.H., Fan, Y., 2025. The improvement of wind comfort and natural ventilation in high-rise building vertical gardens with adjustable louver angles. *Build. Environ.* 285, 113638. <https://doi.org/10.1016/j.buildenv.2025.113638>

- Tjuatja, S., Wibowo, A.P., 2025. Kajian Bibliometrik Windcatcher untuk Ventilasi Alami dan Efisiensi Energi. *J. Arsit. ARCADE* 9, 494-506.
- Tominaga, Y., 2024. CFD simulations of turbulent flow and dispersion in built environment: A perspective review. *J. Wind Eng. Ind. Aerodyn.* 249, 105741.
- Tominaga, Y., Shirzadi, M., 2021. Wind tunnel measurement of three-dimensional turbulent flow structures around a building group: Impact of high-rise buildings on pedestrian wind environment. *Build. Environ.* 206, 108389. <https://doi.org/10.1016/j.buildenv.2021.108389>
- Tominaga, Y., Stathopoulos, T., 2012. CFD modeling of pollution dispersion in building array: evaluation of turbulent scalar flux modeling in RANS model using LES results. *J. Wind Eng. Ind. Aerodyn.* 104, 484-491.
- Tominaga, Y., Stathopoulos, T., 2011. CFD modeling of pollution dispersion in a street canyon: Comparison between LES and RANS. *J. Wind Eng. Ind. Aerodyn.* 99, 340-348.
- Toparlar, Y., Blocken, B., Vos, P., Van Heijst, G.J.F., Janssen, W.D., van Hooff, T., Montazeri, H., Timmermans, H.J.P., 2015. CFD simulation and validation of urban microclimate: A case study for Bergpolder Zuid, Rotterdam. *Build. Environ.* 83, 79-90. <https://doi.org/10.1016/j.buildenv.2014.08.004>
- UGREEN, 2024. Mastering the Breeze: The Comprehensive Guide to Windcatchers [WWW Document]. [ugreen.io](https://ugreen.io/mastering-the-breeze-the-comprehensive-guide-to-windcatchers/). URL <https://ugreen.io/mastering-the-breeze-the-comprehensive-guide-to-windcatchers/> (accessed 10.18.25).
- United Nations Environment Programme, 2021. Global Status Report 2021 105.
- Veerendra, G.T.N., Dey, S., Mantle, E.J., Manoj, A.V.P., Padavala, S.S.A.B., 2025. Building information modeling - simulation and analysis of a University Edifice and its environs - A sustainable design approach. *Green Technol. Sustain.* 3, 100150. <https://doi.org/10.1016/J.GRETS.2024.100150>
- Ventures, C.L., 2025. Iklim dan Cuaca Rata-Rata Sepanjang Tahun di Kota Magelang [WWW Document]. Weather Spark. URL <https://id.weatherspark.com/y/121518/Cuaca-Rata-rata-pada-bulan-in-Kota-Magelang-Indonesia-Sepanjang-Tahun#Figures-WindSpeed>
- Vranešević, K.K., Ćorić, S., Glumac, A.Š., 2023. LES study on the urban wind energy resources above the roof of buildings in generic cluster arrangements: Impact of building position. *J. Wind Eng. Ind. Aerodyn.* 240, 105503.
- Waheeb, M.I., Hemeida, F.A., 2022. Study of natural ventilation and daylight in a multi-storey residential building to address the problems of COVID-19. *Energy Reports* 8, 863-880.

- Wang, B., 2013. Interaction between wind-driven and buoyancy-driven natural ventilation, in: *Building Simulation 2013*. IBPSA, pp. 259-266.
- Wijaya, Y.M., Pasila, F., 2025. AI-Driven Smart HVAC & Building Automation in Asia: A Revolution in Energy Efficiency and Comfort. *Insinyur, Universitas Kristen Petra. J. Dimens. Ins. Prof.* 3, 32-39. <https://doi.org/10.9744/jdip.3.2.32-39>
- Xie, X., Luo, Z., Grimmond, S., Sun, T., 2023. Impact of building density on natural ventilation potential and cooling energy saving across Chinese climate zones. *Build. Environ.* 244, 110621.
- Zhai, Y., Arens, E., Elsworth, K., Zhang, H., 2017. Selecting air speeds for cooling at sedentary and non-sedentary office activity levels. *Build. Environ.* 122, 247-257.
- Zhang, H., Tao, Y., Shi, L., 2021. Solar Chimney Applications in Buildings 409-422.
- Zhang, H., Tao, Y., Zhang, G., Tam, V.W.Y., Fan, C., Shi, L., 2022a. Ventilation performance of solar chimney integrated into a multi-storey building. *Sustain. Energy Technol. Assessments* 54, 102868. <https://doi.org/10.1016/j.seta.2022.102868>
- Zhang, H., Tao, Y., Zhang, G., Tam, V.W.Y., Fan, C., Shi, L., 2022b. Ventilation performance of solar chimney integrated into a multi-storey building. *Sustain. Energy Technol. Assessments* 54, 102868.
- Zheng, X., Montazeri, H., Blocken, B., 2022. Impact of building façade geometrical details on pollutant dispersion in street canyons. *Build. Environ.* 212, 108746.
- Zhong, H.Y., Sun, Y., Shang, J., Qian, F.P., Zhao, F.Y., Kikumoto, H., Jimenez-Bescos, C., Liu, X., 2022. Single-sided natural ventilation in buildings: a critical literature review. *Build. Environ.* 212, 108797. <https://doi.org/10.1016/J.BUILDENV.2022.108797>
- Zhu, Y., Tan, H., Wang, J., 2021. Energy savings through optimal natural ventilation design in tropical climates. *Energy Build.* 245, 111035. <https://doi.org/10.1016/j.enbuild.2021.111035>
- Ziarani, N.N., Cook, M.J., Freidooni, F., O'Sullivan, P.D., 2023. The role of near-façade flow in wind-dominant single-sided natural ventilation for an isolated three-storey building: An LES study. *Build. Environ.* 235, 110210.
- Zoure, M., Genovese, E., 2023. Passive design strategies to mitigate climate change in buildings: A review on natural ventilation. *J. Sustain. Archit.*