Impact of solar shading & ventilative cooling control strategies on the resilience of residential buildings to overheating

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ABSTRACT

The Renson One residential concept focusses on the building envelope and the mechanical installations to ensure a climate-adaptive and resilient design throughout the year. Passive, renewable and energy-efficient elements are combined to address the total indoor environment and energy consumption, based on integrated control mechanisms. The high potential of external shading and ventilative cooling was proved to limit overheating and cooling consumption. Adding manual control of the windows to the simulations is a challenge to better approach reality.

KEYWORDS

Overheating, resilience, passive cooling measures, simulations

1 INTRODUCTION

Summertime overheating is increasingly common in both new and existing homes, even in temperate climates (Lomas, 2001; Otaegi et al., 2022; Attia et al., 2023; Farrokhirad et al., 2024). As the demand for effective solutions and adapted regulations grows, it is crucial to address overheating in an energy-efficient manner. This is a key focus of the Renson One concept. This study examines the impact of external solar shading and ventilative cooling (VC) on thermal comfort during summer and the associated energy consumption in residential buildings.

2 RENSON ONE CONCEPT

Since 2000, Renson has been developing solutions aimed at "Creating Healthy Spaces" in the building sector. The Renson One concept initially centered around adaptive building envelope elements, such as natural ventilation, external solar shading, and ventilative cooling. Over time, energy-efficient HVAC systems with integrated control mechanisms were incorporated to enhance the concept for residential applications (see Fig. 1). A key component of the concept is air-water heat pump technology, which aligns well with renewable energy systems. Automated operation and cloud connectivity further simplify the complexity for inhabitants.

To ensure optimal HVAC system performance, the entire process—design, installation, commissioning, and ongoing operation—must be managed with high quality (O'Hegarty et al., 2022; Mustakallio et al., 2023). The Renson concept is designed to support this comprehensive approach. While balancing energy consumption with comfort, the concept also enhances the resilience and robustness of dwellings. The building envelope plays an equally crucial role as mechanical systems (e.g., heat pumps, fans):

- Energy demand for heating and cooling is minimized through reduced heat losses in winter and low solar gains in summer via solar shading, considering an appropriate window-to-wall ratio (WWR).
- Residents have the option to manually open façade elements for hygienic ventilation, intensive ventilation, or ventilative cooling, leveraging the outdoor environment to enhance living comfort at no additional cost.

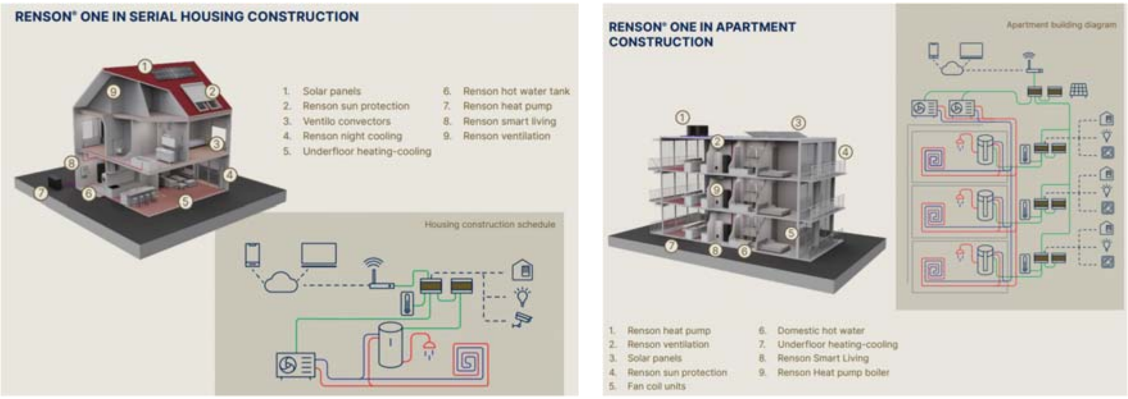

Figure 1: The Renson One concept applied in single- and multi-family buildings

This dual focus on the building envelope and mechanical installations ensures a climate-adaptive and resilient design that functions optimally throughout the year. The Renson One concept is founded on the following principles:

- Build tight, but allow for openings.
- Insulate right and protect from solar heat.
- Ventilate, heat, and cool intelligently and sustainably.

3 OVERHEATING

The Renson One concept encompasses the total indoor environment, addressing indoor air quality (IAQ), thermal comfort across all seasons, acoustic comfort, and visual comfort.
Comfort is considered both in terms of time and space, focusing on providing comfort during periods of occupancy. Moreover, comfort is more critical in habitable spaces, where people spend more time, than in functional rooms (see Table 1).

Table 1: Comfort considerations by room type during occupancy

	Habitable rooms/Kitchen	**Bathroom**	**WC/Laundry**
IAQ	X	X	X
Thermal comfort (heating period)	X	X	▨
Thermal comfort (cooling period)	X	▨	▨
Acoustic comfort	X	X	X
Visual comfort	X	▨	▨

This study is limited to the resilience of the concept to overheating. Summer comfort in buildings is achieved through a dynamic balance between heat gains, heat losses, and heat storage. Renson's approach to enhancing summer comfort involves three key strategies: minimizing solar heat gains, maximizing heat losses, and employing high-temperature cooling with minimal energy consumption.

Solar gains, often the most significant factor affecting indoor temperatures, are influenced by the solar irradiation I (W/m²), the glazing area A_g (m²), and the total solar factor g_{tot} (-) of the windows. To reduce these solar gains, Renson's building concept lowers the solar factor of transparent facade elements by incorporating external solar shading, particularly smart vertical blinds. Fixed horizontal overhangs, such as balconies, are less effective as they reduce solar gains in winter and limit daylight throughout the year.

The next step in the Renson approach is to remove any remaining internal heat passively through natural ventilative cooling. This strategy is complemented by active cooling methods, such as floor cooling or convectors, when necessary. Additionally, the building's total thermal capacity plays a crucial role in moderating indoor temperature fluctuations during both summer and winter. This capacity can be effectively utilized through surface cooling or heating systems to enhance overall comfort year-round.

3.1 Active heating & cooling

Within Renson one, active heating and cooling in residential buildings utilize air-water heat pump (HP) technology with an inverter-driven approach. This technology allows for weather-dependent, controlled low-temperature heating and high-temperature cooling, enabling a wide modulation of heating and cooling capacity and ensuring high efficiency. The system includes an on/off controlled built-in circulation pump to maintain sufficient water flow. However, no built-in electrical backup is provided, so accurate heat loss calculations are essential during the building design phase to ensure that the maximum heating demand is met, unless an additional external backup is planned.

In the West-European climate, well-insulated, airtight dwellings can achieve seasonal heating efficiencies (SCOP) of 4 to 5 with current technologies. For buildings with a net heating demand ranging from 20 to 50 kWh/m² per year, the electricity consumption for space heating remains between 4.0 and 12.5 kWh/m² per year. When operating in cooling mode, the seasonal efficiency (SEER) is at least 3.

For surface heating, with a setpoint temperature of 20°C and a heat transfer coefficient of 8 W/(m²·K), the heating capacity can reach approximately 90 W/m². In cooling mode, with a setpoint temperature of 24°C and a heat transfer coefficient of 6 W/(m²·K), the cooling capacity is around 30 W/m².

In multi-family buildings, a cascade of heat pumps can be used to eliminate the need for central heat storage, which can otherwise result in space loss, heat loss, and higher investment costs. This cascade system allows for a high degree of capacity modulation.

For single-family homes, the heat pump solely produces sanitary hot water (SHW). In multi-family buildings, SHW is generated for each apartment using a separate SHW heat pump storage unit that is integrated into the two-pipes circuit of the heating/cooling system. This SHW unit operates in parallel with the floor heating/cooling system, providing hot water while slightly cooling the heating/cooling circuit. These functions complement each other during cooling periods but are non-complementary during heating periods.

In multi-family buildings, the hydraulic heating and cooling systems are controlled by a building management system at both collective and individual levels. This system uses a unique method called the critical path approach, where the control damper of the critical apartment—

determined by the current heating or cooling demand—is fully opened. This approach continuously monitors and minimizes water flow resistances to save energy. Additionally, the system allows for intelligent heating and cooling of different building areas, exposed to varying solar irradiation levels or internal heat gains.

This electrically-driven building concept is well-suited for integration with renewable electricity production, such as roof-installed or building-integrated photovoltaics (BIPV). This integration can significantly reduce both the final and primary energy consumption for HVAC systems.

3.2 Simulation of summer comfort and energy consumption

Methodology

A dynamic, zonal simulation using Dymola/Modelica/Ideas was conducted to evaluate the impact of solar shading and floor cooling on summer comfort and energy consumption (heating/cooling) in a single-family dwelling. The study focused on the existing Renson concept home, a detached two-story house completed in 2019 in Waregem, Belgium.

This residence, with a square layout, encompasses a total net floor area of 177 m² and includes two bedrooms, a polyvalent room, a bathroom, a living room with an open kitchen, and a technical room (as shown in Fig. 2). The house features a wall with a U-value of 0.15 W/m²·K, a window-to-wall ratio (WWR) of 0.27, and a building airtightness of 3 vol/h at 50 Pa. It has achieved a Belgian energy performance score of E13, corresponding to an A label.

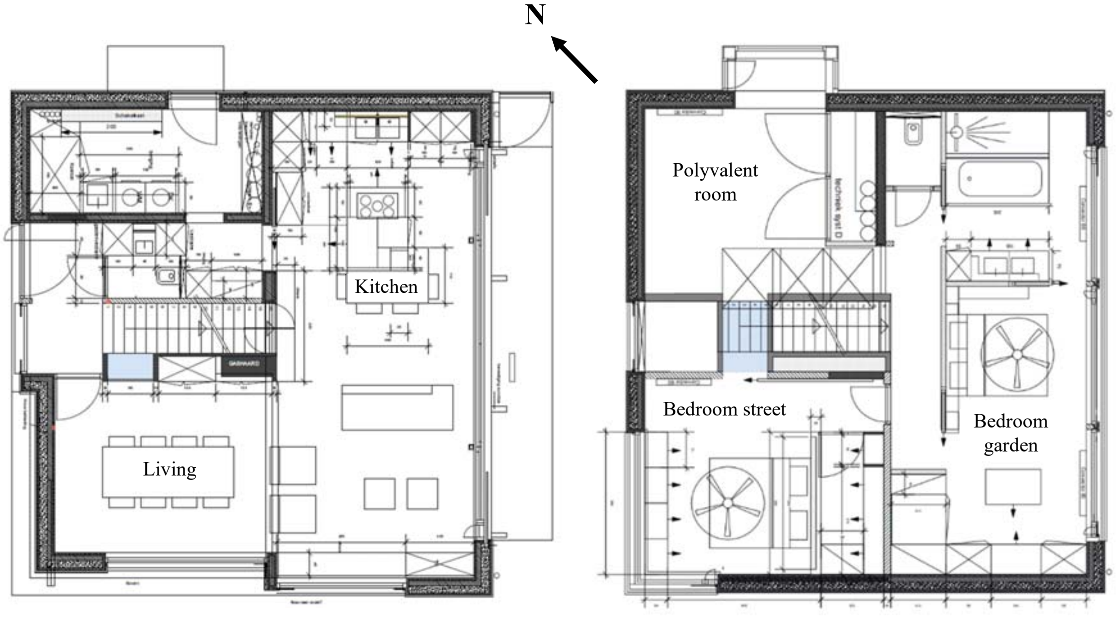

Figure 2: The building layout: left is ground floor, right is upper floor

The home is equipped with a demand-controlled mechanical extract ventilation system, the Healthbox 3.0 Smartzone, which locally adjusts airflow rates based on CO_2, RH, and VOC levels. This system provides natural air supply in habitable rooms and extracts air from both wet and habitable spaces. All windows, including the roof windows in the night hall, are fitted with external blinds, achieving a total solar factor (g_{tot}) of 0.1. Although the kitchen features a fixed horizontal overhang, it was not included in the simulation.

The simulated scenario involved a family of four, including two children, with the sensible heat generated by these occupants being the only internal heat source considered. For the purpose of the study, all windows were kept permanently closed, which is a deviation from real-life conditions. The effects of window use during both daytime and nighttime will be explored in subsequent studies.

Controls and criteria

The control of climate systems in buildings can be managed manually or through automated methods, incorporating rules, predictions, models, and machine learning techniques (Peng et al., 2022). In the simulations conducted, specific temperature setpoints were maintained for different rooms: 20°C for the living room and kitchen, 18°C for the bedrooms, and 22°C for the bathroom. During active cooling, all rooms except the bathroom were cooled to an ideal setpoint of 24°C, which aligns with common practice. The demand-controlled mechanical extract ventilation (DC MEV) system was simulated as it operates in real-life scenarios, adjusting local air flow rates according to the needs.

HVAC systems typically utilize demand control, where system adjustments are made based on real-time needs. In contrast, solar shading is often automated solely based on outdoor climate conditions. Demand control represents a form of closed-loop control, where feedback is provided to ensure the desired outcome is achieved.

For the simulation, the standard ISO/FDIS 52016-3 (2023) was used to derive both automated and manual control strategies for external vertical blinds. Manual control was simulated based on a probabilistic model, where blinds were opened or closed linked to indoor and outdoor conditions when a person entered or left a room, with a minimum interval of four hours between actions. For rule-based automated controls, the following strategies were analyzed:

- Activation based on outdoor irradiation levels (250-300 W/m²) and a predicted maximum outdoor temperature of at least 21°C for the following day.
- Activation based on indoor temperature, implementing a demand-controlled approach.

As a reference, simulations were also conducted for scenarios where external blinds remained permanently up or down.

In this study, the windows were kept closed because accurately modelling real window control is challenging. However, to achieve results that are closer to reality, manual window control will be incorporated into the model, similar to the approach used for solar shading control.

To evaluate the effectiveness of these different control strategies, summer comfort at the room level was assessed using temperature-weighted exceedance hours, known as degree-hours in Kh, for temperatures exceeding 24°C and 26°C by a margin of +0.5°C (Fig. 3). This method provides a more accurate measure of overheating than simply counting hours above a temperature threshold, which can be misleading. Additionally, the yearly cooling demand required to maintain a set temperature of 24°C was calculated and compared with the heating demand (Fig. 4).

Results

As illustrated in Fig. 3, without active cooling, temperature exceedances are relatively consistent across different habitable rooms. Minor variations are primarily due to differences in window-to-wall ratios (WWR), such as the reduced overheating observed in a bedroom with a low WWR on the west corner. In scenarios without cooling, solar shading, or openable windows, the degree-hours exceeding 24°C and 26°C are alarmingly high, around 56 kKh and 46 kKh respectively, indicating significant overheating. Under these conditions, indoor temperatures can rise to 35-40°C, even when outdoor temperatures are 10°C lower (25-30°C). This highlights the risk of overheating not just during summer but across at least 50% of the year, especially in energy-efficient homes with high glazing-to-wall ratios and no solar shading means.

Solar shading plays a crucial role in mitigating this overheating, especially when windows remain closed. The use of solar shading can reduce temperature exceedance by 50% to 67% at thresholds of 24°C and 26°C. The effectiveness of manual shading control is comparable to that of automated systems based on solar radiation and outdoor temperature. Inhabitants' ability to respond to indoor temperature changes in manual control scenarios and the presence of usually at least one person of the family, accounts for the relatively high performance of manual control. Even with solar shading, degree-hours still range between 15-25 kKh, corresponding to an average air temperature near 30°C during overheating. The well-insulated house with permanently closed windows and the quite high shading control levels of 250-300 W/m², explain this high temperature exceedance. This result reflects and underscores the importance of addressing summer comfort in building design.

To explore the full potential of solar shading in reducing overheating, simulations were conducted with blinds permanently closed. This approach significantly improved summer comfort by virtually reducing the window area by 90%, thus minimizing solar gains. However, for optimal comfort, solar shading may need to be deployed more frequently than is typical in practice. A more responsive shading strategy could involve lower outdoor setpoints or demand-controlled mechanisms based on indoor temperature. Controlling shading in response to indoor comfort temperature (as indicated by a thermostat, for instance) also proved effective in maintaining summer comfort (Fig. 3). When shading is often fully closed, blinds are preferable to rolling shutters, for enhanced visual contact with the outdoors.

Additionally, the study analyzed the potential of floor cooling with a limited capacity of 30 W/m_{fl}^2. With a total available cooling capacity of approximately 4 kW or 70 W/m² window area, floor cooling can maintain summer comfort even without solar shading when outdoor temperatures are below 30°C. However, during heatwaves with temperatures reaching 35-40°C, the combination of solar shading and keeping windows closed during the day becomes essential to maintain a comfort temperature of 24°C.

While high-temperature floor cooling operates efficiently, its capacity is restricted to prevent condensation on the floor when the indoor air dew point is high. Increasing cooling capacity by lowering water temperature raises the risk of condensation, especially when windows are opened. Thus, to maintain the desired 24°C comfort level, solar shading is recommended to supplement the limited floor cooling capacity.

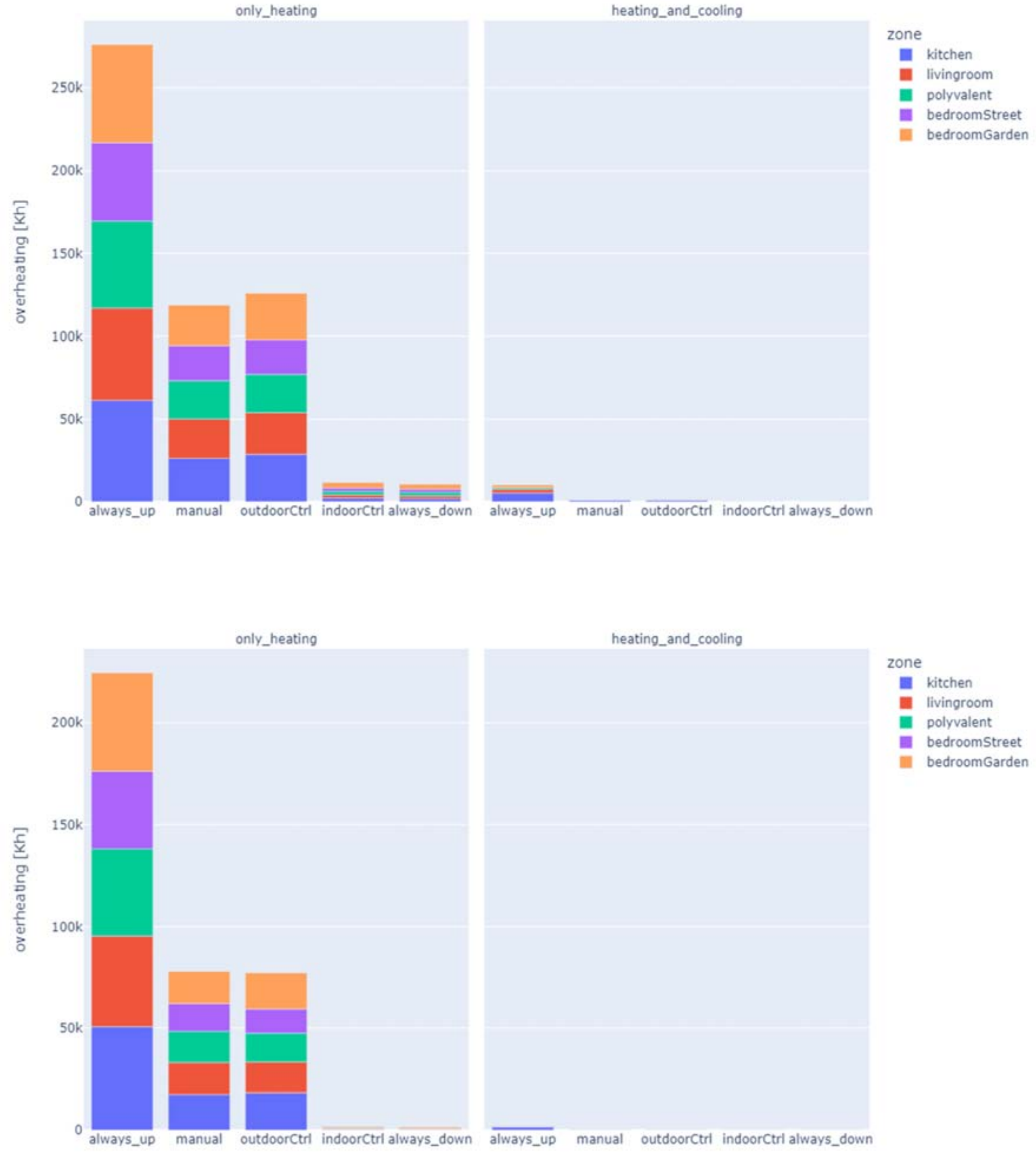

Figure 3: Overheating degree-hours (Kh) on room level above 24°C (top) and 26°C (bottom) for different external shading controls, without active cooling (left) and with active cooling (right)

Fig. 4 presents the energy demand for cooling and heating per conditioned floor area. The data clearly show the shift in new dwellings from heating challenges to cooling challenges. The energy required for heating is only half that needed for cooling. Without solar shading or openable windows, cooling demand is nearly four times that of heating. Implementing solar shading with suboptimal control almost halves the cooling demand to 40 kWh/m². The total cooling demand is approximately 5000 kWh or 1500 kWh of final energy, which can be partially generated by PV systems.

The required heating demand is around 20 kWh/m^2 or 3000 kWh, equating to 600-750 kWh of annual heating consumption. Heat gains, whether solar or internal, significantly impact this demand, which can double if solar gains are reduced by obstructions near the dwelling or excessive use of solar shading. Although floor cooling can prevent remaining overheating, its cooling capacity is limited. Future simulations will explore the impact of heatwaves on overheating issues. Additionally, designing a cost-effective house could involve limiting WWR on solar-exposed façades to permanently reduce both capital and operational expenditures.

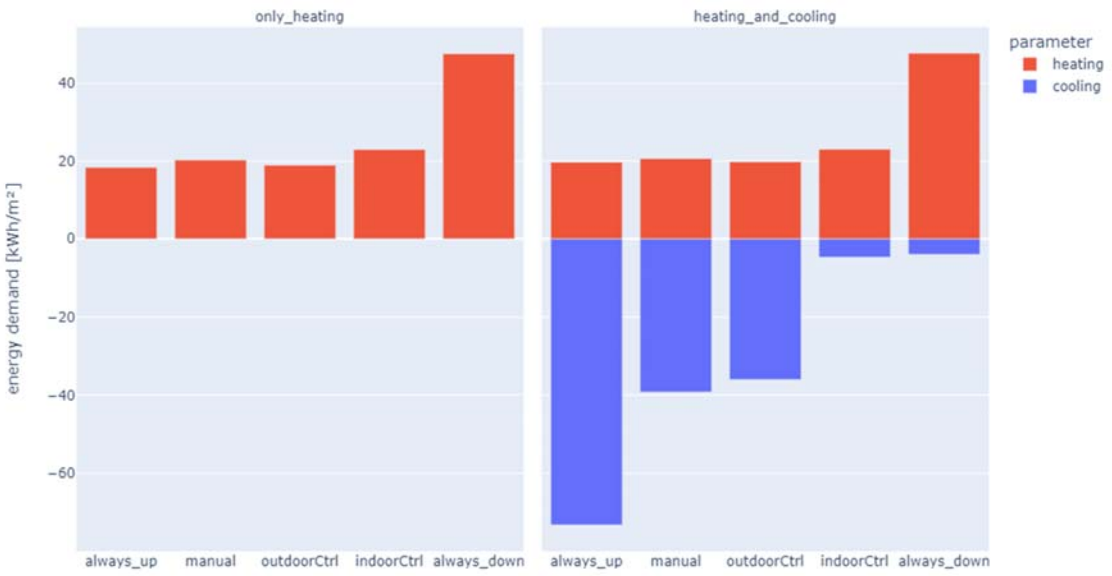

Figure 4: Heating and cooling demand (kWh/m^2) on building level for different shading controls, without active cooling (left) and with active cooling (right)

3.3 Passive ventilative cooling (VC)

The impact of VC through openable windows, which are usually present in habitable rooms, can be substantial for maintaining summer comfort (Foldbjerg et al., 2014). This passive cooling method, driven by natural forces, is fully renewable and offers significant potential cooling capacity, though it is variable and uncertain across time and space. The cooling potential of VC is approximately 4 W/m^2 per air exchange, assuming an average outdoor-indoor temperature difference of 5°C. The effectiveness of this passive cooling is largely influenced by pressure differences, which average around ±1 Pa across facade ventilation elements. This pressure difference can facilitate a ventilation rate of about 30 m^3/h/m$_{fl}^2$ through a fully open window with a window-to-floor ratio (WFR) of 1%. While the WFR can be as high as 25%, the practical WFR for openable windows typically ranges between 5-10%.

Assuming a room height of 2.5 meters, the ventilation air renewal rate is about 60-120 air changes per hour (ACH). However, this rate can be significantly reduced by factors such as single-sided rather than cross-ventilation (by 50%), tilted versus fully open windows (by 95%), and the use of louvres (by 50%), potentially reducing the ACH to around 1. The maximum opening angle of the window is crucial in enhancing a building's resilience during heatwaves. Louvres also play a beneficial role by increasing the likelihood that VC openings will be effectively used. These multifunctional devices help prevent the entry of rain, insects, noise, and unauthorized persons, thereby encouraging the use of VC.

The presence or absence of active cooling systems greatly influences how frequently VC devices, such as windows, are utilized. Without an active cooling system, occupants are more likely to open windows to manage indoor temperatures. Therefore, summer comfort simulations that assume windows remain closed are unrealistic and will be the subject of further investigation. Similar to solar shading, the control conditions of VC devices are critical. Manual control of VC, without the need for actuators, provides an essential means of cooling, particularly if technical devices fail or during power outages.

4 CONCLUSIONS

The Renson One concept approaches sustainable and resilient design through several key strategies:

- Implementing an efficient heating, cooling, and ventilation system.
- Combining passive and renewable cooling methods.
- Utilizing a single control system to integrate all climate control devices.
- Opting for cloud-based control over local systems to minimize the need for numerous detection mechanisms.
- Incorporating PV technology, partially integrated into building envelope products.

The dynamic control and behavior of the concept is simulated in detail. Generally, new residential buildings have a reduced heat demand due to improved building envelopes, greater compactness, and the impacts of climate change. This shift necessitates a focus on living comfort and energy efficiency during the non-heating months, particularly as this period extends for at least half of the year in Western Europe. Consequently, the challenge lies in preventing overheating during the design phase of well-insulated homes:

- A thorough use of external solar shading on all windows, allows to prevent cooling energy to maintain summer comfort, if no heat waves (>30°C) occur.
- High-temperature cooling methods can also significantly diminish overheating hours even without external shading. Nevertheless, solar shading is advisable for rooms oriented from east to west that feature substantial glazing. Ultimately, the key principle for ensuring summer comfort is to limit solar gains relative to floor area.
- During periods of extreme heat, a combination of external solar shading and high-temperature cooling becomes essential for maintaining a comfortable indoor environment, thereby significantly reducing electricity consumption, even from renewable sources.
- Manual control of solar shading can provide relatively good performance in case of conscious and present inhabitants.
- Additionally, openable windows usually present in habitable rooms can serve as a passive and renewable measure for ventilative cooling, enhancing the sustainability and heat resilience of residential buildings. Modelling of a real manual window control stays a challenge.
- Louvres improve the window performance in term of water tightness, insect-protection, and burglary resistance, increasing in that way the time in use of VC.

5 ACKNOWLEDGEMENTS

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A more comprehensive discussion on the Renson One concept, including its broader implications for indoor environments, is available.

6 REFERENCES

Attia, S., Caroline Benzidane, C., Rahif, R. et al. (2023). Overheating calculation methods, criteria, and indicators in European regulation for residential buildings. *Energy & Buildings*, 292, 2023, 113170. https://doi.org/10.1016/j.enbuild.2023.113170.

Farrokhirad, E., Gao, Y., Pitts, A. & Chen, G. (2024). A Systematic review on the risk of overheating in passive houses. *Buildings* 2024, 14, 2501. https://doi.org/10.3390/buildings14082501.

Foldbjerg, P., Asmussen, T., Fedkenheuer, M. & Holzer, P. (2014). Self-evaluated thermal comfort compared to measured temperatures during summer in three active houses where ventilative cooling is applied. 35th *AIVC Conference*, Poznań, Poland, 24-25 September 2014.

ISO/FDIS 52016-3 (2023). Energy performance of buildings — Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads — Part 3: Calculation procedures regarding adaptive building envelope elements.

Lomas, K. J. (2021). Summertime overheating in dwellings in temperate climates. *Buildings and Cities*, 2(1), pp. 487–494. DOI: https://doi.org/10.5334/bc.128

Mustakallio, P., Schild, P. & Ekberg, L. (2023). Challenges and needed remedies of demand controlled ventilation. *Rehva Journal*, April 2023, 13-17.

O'Hegarty, R., Kinnane, O., Lennon, D. & Colclough, S. Air-to-water heat pumps: Review and analysis of the performance gap between in-use and product rated performance. *Renewable and Sustainable Energy Reviews* 155 (2022) 111887. https://doi.org/10.1016/j.rser.2021.111887

Otaegi, J., Hernández, R.J., Oregi, X., Martín-Garín, A. & Rodríguez-Vidal, I. (2022) Comparative analysis of the effect of the evolution of energy saving regulations on the indoor summer comfort of five homes on the coast of the basque country. *Buildings* 2022, 12, 1047. https://doi.org/10.3390/ buildings12071047.