

PAPER • OPEN ACCESS

## Effect of cavity ventilation on hygrothermal performance of a heavyweight building envelope

To cite this article: Marina Bagarić *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **609** 032033

View the [article online](#) for updates and enhancements.

You may also like

- [Thermal buckling of double-layered graphene system in humid environment](#)  
Mohammed Sobhy and Ashraf M Zenkour
- [Experimental and Numerical Investigation of Mould Growth Risk on Wooden Load-Bearing Structure in Hemp-lime Concrete Facades](#)  
S Petersen, S Svendsen and M Hahn-Hundsahl
- [Acceleration of degradation by highly accelerated stress test and air-included highly accelerated stress test in crystalline silicon photovoltaic modules](#)  
Soh Suzuki, Tadanori Tanahashi, Takuya Doi *et al.*



**ECS**  
The  
Electrochemical  
Society  
Advancing solid state &  
electrochemical science & technology

**DISCOVER**  
how sustainability  
intersects with  
electrochemistry & solid  
state science research

# Effect of cavity ventilation on hygrothermal performance of a heavyweight building envelope

Marina Bagarić<sup>1,\*</sup>, Ivana Banjad Pečur<sup>1</sup>, Bojan Milovanović<sup>1</sup>

<sup>1</sup> University of Zagreb, Faculty of Civil Engineering, Department of Materials

\* mbagarić@grad.hr

**Abstract.** This study investigates the effect of air cavity ventilation on hygrothermal performance of a heavyweight building envelope constructed with ventilated prefabricated wall panels. The specificity of panels lies in utilization of recycled construction and demolition waste for production of recycled aggregate concrete (RAC). To evaluate the long-term hygrothermal performance of presented envelope, an in-situ monitoring system was designed and commissioned in three-story family house in City of Koprivnica, Croatia. Temperature and humidity distribution through all characteristic layers - outer RAC façade layer, air cavity, thermal insulation and inner RAC layer - was observed for differently-oriented wall panels. By analyzing the first-year monitoring results it was found that ventilation helped to maintain acceptable relative humidity levels in thermal insulation. Moreover, it was observed that cavity ventilation decreased surface temperature of thermal insulation in summer period and increased it in winter period, thus resulting with lower overall heat loss compared to non-ventilated envelope system. This positive effect of cavity ventilation on hygrothermal performance was influenced by wall orientation, with the most pronounced effect being exhibited for the south-oriented wall panel.

## 1. Introduction

Construction sector has an enormous impact on our environment. Just in Europe, 40% of energy consumption and 50% of material resources taken from nature are construction related; moreover, 30 – 50% of European national waste production comes from construction sector [1]. Transition of construction sector towards sustainability is being strongly required by European legislation and supported by scientific and professional community. Our built environment can be considered as sustainable resource of raw materials that can be reused and recycled for production of new construction materials, systems and structures. One possible example is using construction and demolition waste (CDW) as recycled aggregate for production of new concrete. Recycled aggregate concrete (RAC) has been recognized as sustainable alternative for conventional concrete. Extensive research activities concerning mechanical and durability properties of different types of RAC have been (and still are) conducted [2-4], while quite fragmented knowledge is present about RAC hygrothermal properties [5-7]. Hygrothermal characterization at material scale, and especially at large scale, is prerequisite for trustworthy prediction of building's hygrothermal behaviour. Hygrothermal behaviour implies the behaviour of building when exposed to heat, air and moisture loads from outdoor and indoor environment. It is important aspect of building's overall performance and directly influence its energy need, service life, indoor thermal comfort and indoor air quality [8]. This paper deals with hygrothermal characterization of an innovative wall assembly consisting of two different RAC layers.

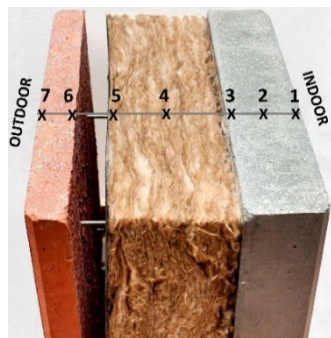
## 2. Ventilated prefabricated wall panel from recycled aggregate concrete

Comprehensive research at material scale was conducted to optimize mix design of two concrete types from mechanical and durability aspects. This has resulted with replacing 50% of natural aggregate with recycled [5]. Hygrothermal characterization at material scale included the basic thermal and hygric



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

properties [9]. Upscaling RAC from laboratory material experiments to large scale resulted with development of innovative ventilated prefabricated sandwich wall panel (Fig 1). Presented panel



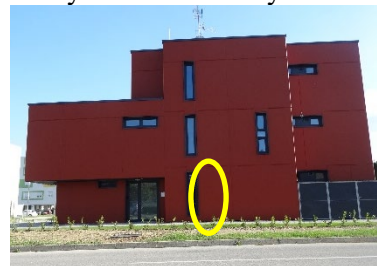
**Figure 1.** Ventilating prefabricated RAC wall panel

consists of 12 cm thick inner RAC layer, 20 cm of formaldehyde-free mineral wool thermal insulation, 4 cm thick air cavity and 6 cm of outer RAC façade layer. The specificity of this panel lies in utilisation of CDW and air cavity with naturally ventilated air (which is not common in conventional concrete sandwich panels). In inner RAC layer 50 % of natural aggregate is replaced with recycled aggregate from old demolished concrete structures, while in outer RAC façade layer 50 % of natural aggregate is replaced with recycled brick from brick manufacturing process. Panel unifies at the same time the role of external wall and façade, and by being completely produced in controlled conditions in precast factory it can speed up construction process. With steady-state U-value of  $0.16 \text{ W/m}^2\text{K}$  panels are suitable for constructing buildings

with very low-energy demand. Surface mass over  $400 \text{ kg/m}^2$  classifies this wall panel as heavyweight, whereas high thermal mass potentially can be beneficial from the aspect of building heating and cooling energy need. To investigate the suitability of RAC for very low-energy, moisture safe and sustainable



a)



b)

**Figure 2.** House built with ventilated prefabricated RAC wall panels: a) south façade, b) north façade

building envelopes at large scale, family house (Fig 2) was built with presented panels and an in-situ experimental monitoring of hygrothermal performance was commissioned as a proof-of-concept. In the next section experimental setup for the in-situ monitoring will be presented.

### 3. Experimental setup for the in-situ hygrothermal monitoring

The 3-storey family house constructed with ventilated RAC wall panels was built in the City of Koprivnica (HDD 1472) within the socially-supported housing programme. Three wall panels in ground floor were selected for monitoring. Selected panels differ by their orientation and conditions of indoor environment. For the purpose of this paper only south (adjacent to conditioned living room) and north panel (adjacent to unconditioned staircase), marked in Fig 2, will be analysed.

With the main goal to determine hygrothermal performance of ventilated RAC wall panel when exposed to real climate conditions and under the real use of occupants, temperature and relative humidity sensors were installed in all four characteristic layers of selected wall panels, which gives 7 measuring points per panel (Fig 1). All sensors are wired and connected to the central measuring unit located in the staircase, where readings are recorded at hourly basis and further wirelessly transmitted to the dedicated server on Faculty of Civil Engineering in the City of Zagreb. Conditions of outdoor environment are monitored every 5 min at the nearest metrological station, while in living room and staircase temperature and relative humidity are monitored at 15-min basis.

### 4. Influence of thermal mass on energy performance

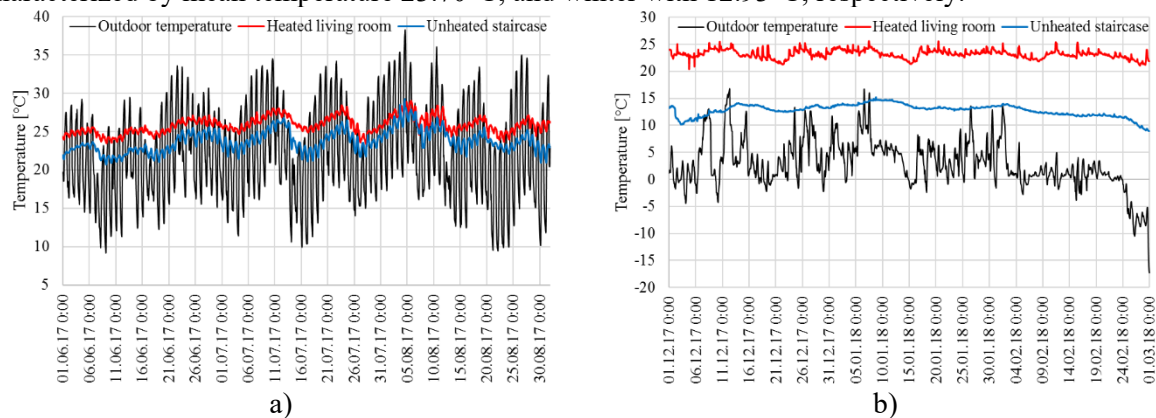
Quasi steady-state calculations according to Standard HR EN ISO 13790 [10] were performed to evaluate the influence of panels high thermal mass on energy performance of an exemplary building. To capture only the influence of opaque elements, exemplary building was modelled without transparent openings. Ventilation losses, thermal bridges and internal gains were also excluded from calculation. Two different locations were observed, the City of Koprivnica – KC (HDD 1472) in Croatian continental climate and the City of Dubrovnik – DU (HDD 382) in Croatian littoral climate. Since energy demand

of building is also depended on occupancy schedule, two different system operating modes were analyzed, i.e. continuous operating mode (00:00-24:00h, 7 days/week) and intermittent operating mode (08:00-23:00h, 7 days/week).

## 5. Results and discussion

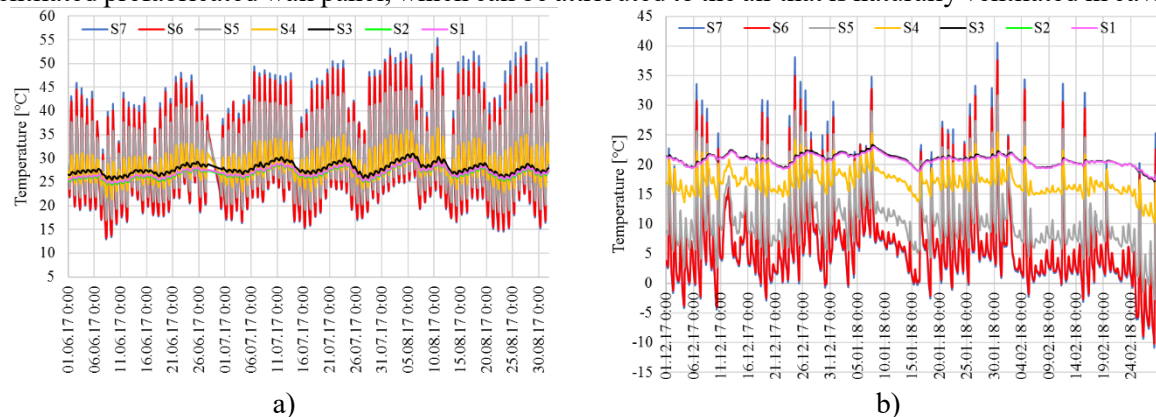
### 5.1. Experimental in-situ monitoring of hygrothermal performance

The 1<sup>st</sup> year monitoring results for summer period (Jun 1, 2017 – Sept 1, 2017) and winter period (Dec 1, 2017 – Mar 1, 2018) are analysed in this subsection. During summer (Fig 3a), the exterior temperature ranged from 38.27°C to 9.19°C with an average of 22.11°C. During winter period (Fig 3b), exterior extremes were 16.77°C and -17.34°C with an average of 2.94°C. Temperature fluctuations of indoor environment were more limited, and for heated living room summer average temperature was 25.82°C, while winter average temperature was 23.19°C. In case of unheated staircase, summer period was characterized by mean temperature 23.70°C, and winter with 12.93°C, respectively.



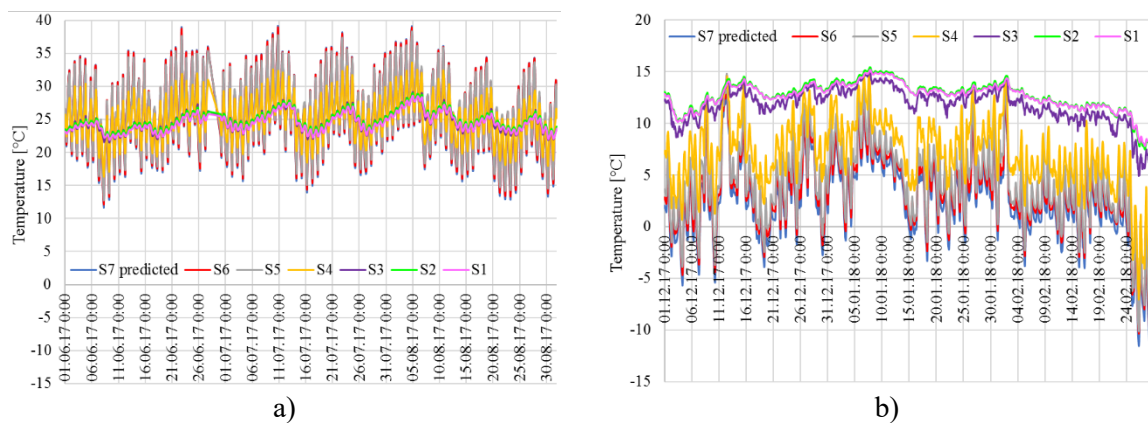
**Figure 3.** Outdoor and indoor environment temperature: a) summer period, b) winter period

After system commissioning, it was detected that some sensors are not working: i) relative humidity of the south panel at positions S1-S3; ii) temperature of the north panel at position S7; iii) relative humidity of the north panel at position S7. Influence of air ventilation can be observed through temperature difference between exterior surface temperature of outer RAC façade layer (S7) and exterior surface temperature of mineral wool layer (S5 position), as shown in Fig 4 and Fig 5. This difference is more pronounced at south panel, with S5 maintaining up to 10.79°C lower temperature compared to S7 during summer. In winter period, the effect is completely opposite, whereas S5 maintains up to 8.08°C higher temperature. This pattern of behaviour indicates the passive cooling and passive heating mechanism of ventilated prefabricated wall panel, which can be attributed to the air that is naturally ventilated in cavity.



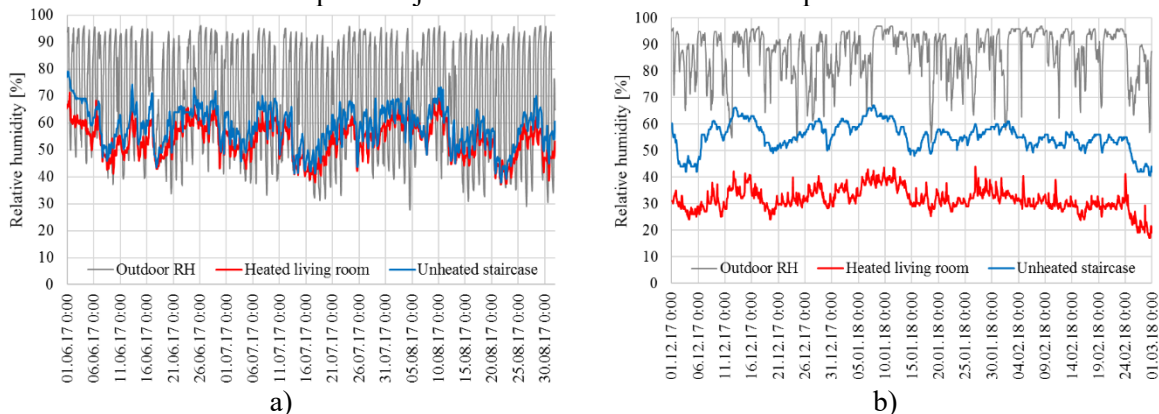
**Figure 4.** Temperature distribution through the south-oriented panel: a) summer period, b) winter period





**Figure 5.** Temperature distribution through the north-oriented panel: a) summer period, b) winter period

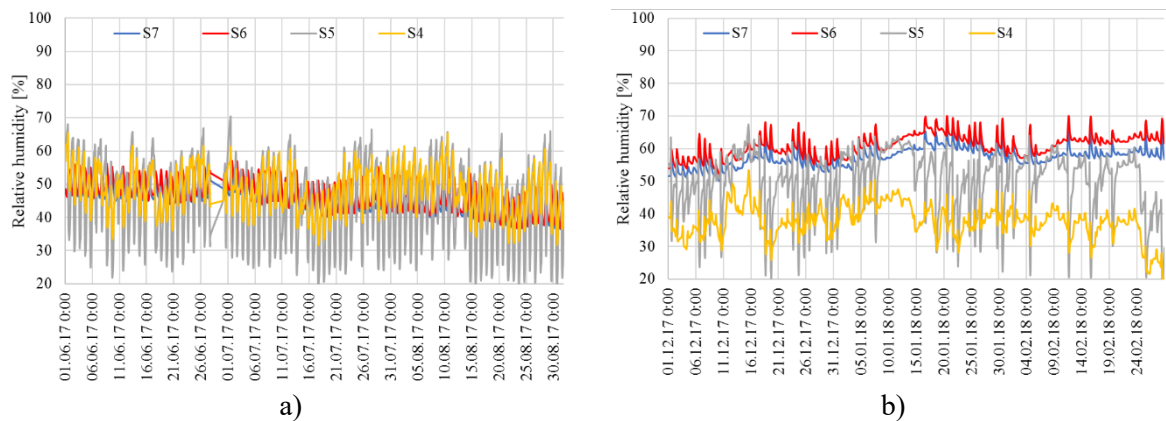
By having no information on S7 temperatures at north panel, it would be difficult to evaluate the influence of air ventilation. However, in 2<sup>nd</sup> monitoring year, temperature sensor started recording and based on those results, regression analysis was applied to predict S7 values for 1<sup>st</sup> monitoring year (marked as S7 predicted in Fig 5). For north-oriented panel, S7-S5 difference is considerably lower (1.74°C in summer period and 2.94°C in winter period), which suggests that ventilation is not extremely beneficial for north oriented panel adjacent to unconditioned interior space.



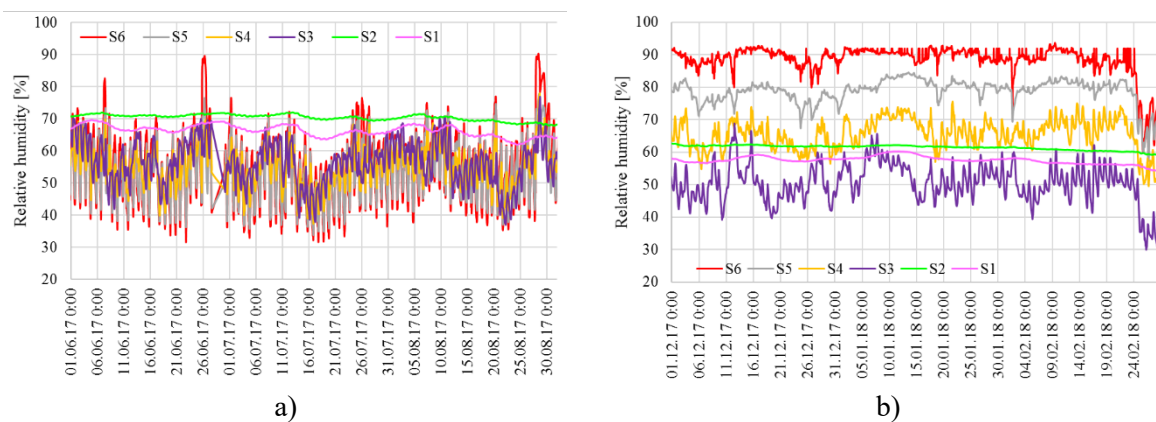
**Figure 6.** Outdoor and indoor environment relative humidity: a) summer period, b) winter period

Exterior relative humidity exceeds 90% during both summer and winter, whereas more expressed fluctuations are present during summer (Fig 6a). Conditioned living room and unconditioned staircase have the same pattern of relative humidity evolution, with similar values in summer. During winter (heating season), deviations between living room and staircase becomes more dominant (Fig 6b).

The primary role of mineral wool layer is thermal protection in winter period. By analysing relative humidity levels in the middle of mineral wool (S4) during winter period (Fig 7b and Fig 8b), the one can observe that for south panel it stays under 50%, while on the other hand for north panel it oscillates between 60-70%. Generally, north panel has higher relative humidity levels during both summer and winter period. This can be correlated to lower ventilation rates due to north orientation.



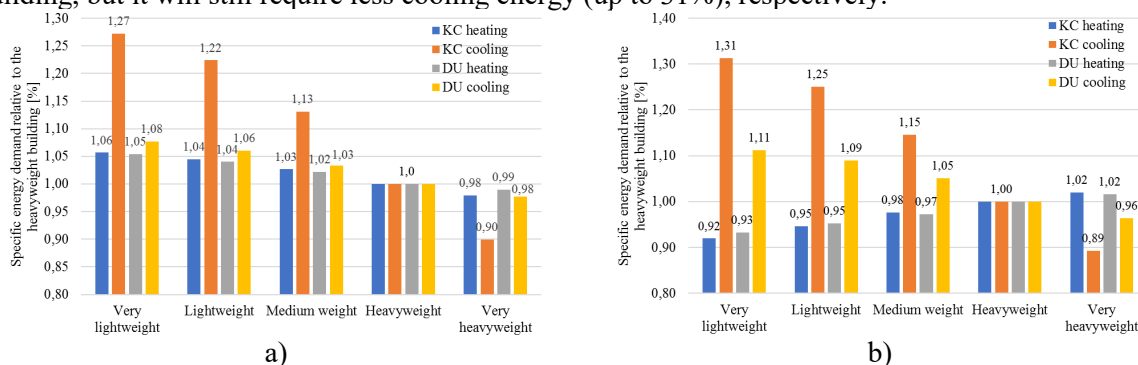
**Figure 7.** Relative humidity distribution through the south-oriented panel: a) summer, b) winter



**Figure 8.** Relative humidity distribution through the north-oriented panel: a) summer, b) winter

### 5.2. Influence of thermal mass on energy performance

For continuous mode, heavyweight building will consume somewhat less heating and cooling energy compared to lighter constructions, and that applies for both climates. Contrary to that, for intermittent mode, heavyweight building can consume up to 8% more heating energy compared to very lightweight building, but it will still require less cooling energy (up to 31%), respectively.



**Figure 9.** Energy demands relative to heavyweight building in two different climates: a) continuous operating mode, b) intermittent operating mode

## 6. Conclusion

The main contribution of the paper is large-scale monitoring of hygrothermal performance of innovative heavyweight building envelope exposed to real outdoor environment and under the real occupants' use. Innovation of envelope lies in ventilated prefabricated sandwich wall panels produced using high

replacement ratio of recycled aggregate (from construction and demolition waste). Naturally ventilated air in cavity (which is not common for conventional concrete sandwich walls) contributed to lowering the surface temperature of thermal insulation layer in summer (passive cooling) and increasing it during winter period (passive heating), respectively. This positive effect of air ventilation is significantly more pronounced for the south-oriented panel compared to the north-oriented panel. Moreover, ventilation in the south panel helped to maintain relative humidity levels in thermal insulation layer under 50% (during winter), while those values were somewhat higher for the north panel. It can be concluded that ventilation is depended on orientation and conditions of the adjacent indoor environment, which then directly influence the hygrothermal performance of building envelope.

In both continental and littoral climate, high thermal mass of analysed wall panels showed to be beneficial from heating and cooling energy demand aspect in case of continuous operating mode (compared to lighter structures). On the other hand, when intermittent occupancy is observed, heavyweight building can consume more energy for heating, but it will still require less cooling energy (compared to lighter structures).

Results indicate that recycled aggregate concrete can be successfully upscaled to innovative wall assembly and used for constructing very low-energy, moisture-safe and sustainable buildings.

### Acknowledgments

Authors kindly acknowledge financial support for in-situ monitoring equipment provided by “ECO-SANDWICH” project (ECO/11/304438/SI2.626301) within EU CIP-ECO Innovation Programme.

### References

- [1] Vyncke J and Vrijders J, Recycling of Construction and Demolition Waste - An Overview of RILEM Achievements and State of the Art in the EU 2016 *Proc. Second Int. Conf. Concr. Sustain.*, Spain
- [2] Behera M, Bhattacharyya SK, Minocha AK, Deoliya R and Maiti S, Recycled aggregate from C&D waste & its use in concrete - A breakthrough towards sustainability in construction sector: A review 2014 *Constr. Build. Mater.* **68** 501–516
- [3] Marco P, A conceptual model to design recycled aggregate concrete for structural applications 2014 *Springer Theses*, Springer
- [4] Pickel D, Recycled Concrete Aggregate: Influence of Aggregate Pre-Saturation and Curing Conditions on the Hardened Properties of Concrete 2014 Thesis for the degree of Master of Applied Science, University of Waterloo, Ontario, Canada
- [5] Banjad Pečur I, Štirmer N and Milovanović B, Recycled aggregate concrete for nearly zero-energy buildings 2015 *Mag. Concr. Res.* **67** 575–584
- [6] Fenollera M, Míguez J, Goicoechea I and Lorenzo J, Experimental Study on Thermal Conductivity of Self-Compacting Concrete with Recycled Aggregate 2015 *Materials* **8** 4457–4478.
- [7] Zhu L, Dai J, Bai G and Zhang F, Study on thermal properties of recycled aggregate concrete and recycled concrete blocks 2015 *Constr. Build. Mater.* **94** 620–628
- [8] Feng C and Janssen H, Hygric properties of porous building materials (II): Analysis of temperature influence 2016 *Build. Environ.* **99** 107–118
- [9] Bagarić M, Banjad Pečur I, Milovanović B and Hozmec S, Ventilated sandwich wall panel from recycled aggregate concrete: Hygrothermal characterization 2019 *Proc. Int. Conf. SMSS2019–Energy Efficient Building Design and Legislation*, Croatia, 102-110
- [10] HZN (Croatian Standards Institute), HRN EN ISO 13790 Energy performance of buildings -- Calculation of energy use for space heating and cooling (ISO 13790:2008; EN ISO 13790:2008)