



Investigation on a Vermiculite-Based Solar Thermochemical Heat Storage System for Building Applications

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TECHNICAL ARTICLE

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ABSTRACT

Industrial processes and the building sector (e.g., for space and water heating) are responsible for the majority of the total energy consumed for heat. Although fossil fuels remain to dominate the heating sector, renewable heating technologies have been lately widely deployed. Thermochemical energy storage (TES) can be a promising advanced technology in addressing the mismatch between renewable energy supplies and the end-user's demand. In this paper, a novel *Vermiculite-based Solar Thermochemical Heat Storage* (VS-THS) system was proposed for domestic space heating applications, which could also overcome the intermittency challenges and realise long-term solar energy storage. A small-scale prototype was set up to evaluate the energy storage performance of the proposed system using a patented ChainStore panel to accommodate vermiculite-based composite. The unique design of the ChainStore arrangement offers great heat and mass transfer and good flexibility for system resizing in the case of varying the building energy demand. Due to the low regeneration temperature (63 °C) and high energy storage density (253.8 kWh/m³) of the vermiculite-based adsorbent impregnated with MgSO₄ and CaCl₂, it was chosen as the THS composite in the experiments. The experimental results showed that the proposed VS-THS is feasible for domestic space heating, with the highest space heating supply temperature of 37.6 °C, and the system COP in the reaction process is 7.9–10.4. In addition, the results also demonstrate that the composite of vermiculite impregnated with MgSO₄ and CaCl₂, with a good water adsorption performance. This proposed concept of VS-THS could be sized for different building applications.

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1 INTRODUCTION

In 2021, heating accounted for 50% of the global final energy consumption (Agency, 2021a). In particular, industrial processes and the building sector (e.g., for space heating and water heating) are responsible for the majority of the total energy consumed for heat. Although fossil fuels remain to dominate the heating sector, low carbon heating solutions have lately attracted more and more attention. It is projected that the global heat demand would expand by 17 EJ during 2021–2026, and the global renewable heat consumption could rise by 5.4 EJ (Agency, 2021b). Considering the environmental problems directly related to energy production and consumption as well as the rising energy price, more regions have established supportive policies to prompt the deployment of renewables. For instance, the UK has committed to reaching Net-Zero by 2050, and the government's ten-point plan for the green industrial revolution has a strong focus on renewables and new energy technologies. Energy-efficient renewable energy technologies are desired to meet the enormous demand during the clean energy transition. However, the mismatch between the renewable energy supplies and the end-users demand is one of the main problems that need to be tackled for sustainable energy systems (Gan et al., 2020).

Energy storage can be a solution to addressing the imbalance of the energy supply-demand on a daily, weekly, and even seasonal basis by effectively storing energy during a changing process and providing the energy when needed at a later time. Thermal energy storage (TES) technology captures the thermal energy by heating or cooling a thermal storage medium for later utilisation in heating, cooling, and power generation applications (Hasnain, 1998). Sensible heat storage (e.g., water, rock, and soil) and latent heat storage (e.g., phase change materials) have been widely adopted in various applications. Both technologies have relatively low energy storage density (i.e., 0.2–0.8GJ/m³), low heat temperature output, short-term storage capability with massive volume requirements, the difficulty of heat control and large heat loss (Aydin et al., 2015, Yu et al., 2013, Lefebvre and Tezel, 2017, Su et al., 2015). Comparatively, thermochemical heat storage (THS) has been regarded as a promising alternative to the conventional TES, which stores energy by an endothermic chemical reaction and releases energy by a reversible reaction (Yan et al., 2015). THS demonstrates high energy storage density at ambient temperature, high exergetic efficiency, low heat loss, low regeneration temperature, low space-demanding and long-term storage stability (Jarimi et al., 2017, Sunku Prasad et al., 2019, Gil et al., 2010).

Solar energy systems have been growing quickly in many countries across the world; nevertheless, these systems suffer from the intermittent, seasonal,

and location-dependent nature of solar energy. THS technologies could be integrated into the solar energy systems to overcome the intermittency challenges and realise the long-term (e.g., seasonal) solar energy storage (Mette et al., 2012). There are different configurations of the thermochemical reactor, such as the widely employed packaged bed reactors, agitated, and fluidised bed reactors (Yan et al., 2022a, Yan et al., 2020, Liu et al., 2021). The design of the reactor also relates to the system configuration (i.e., open or closed systems) and selected thermochemical material of the THS system (Zettl et al., 2014). THS material is the main parameter that influences the performance of the heat storage system. It has been reported that the energy density of THS materials is two times higher than latent energy storage materials and eight to ten times higher than sensible energy storage materials (Aydin et al., 2015). Referring to the studies (Han et al., 2022, Jarimi et al., 2017, Pardo et al., 2014, Dizaji and Hosseini, 2018), several factors are needed for taking into consideration to select a suitable THS material, including:

- High energy storage density;
- Low charging/regeneration temperature;
- High water/sorbate uptake;
- Appropriate heat and mass transfer properties for efficient power output;
- Ease of handling to handle and non-poisonous nature;
- Low-cost price per kW/h of energy stored with thermal stability;
- Application suitability.

Particularly, the thermochemical adsorption heat storage (THS) is based on the reversible sorption process between the solid adsorbent and the liquid adsorbate, with which heat is stored through the endothermic desorption process and is released through the exothermic adsorption process (Yan et al., 2022b). Generally, THS requires lower regeneration temperatures (e.g., <150 °C) (Vasta et al., 2018), which could be met by low-grade heat sources, such as solar energy. THS provides great feasibility and adaptability for domestic applications, as the THS materials could react directly with the atmospheric moisture.

The widely employed adsorbents for THS systems are silica gels, zeolites, metal organic frameworks, activated carbons (Zhao et al., 2021). Recently, composite adsorbent materials have been gaining more research interest, which combines hygroscopic salts and matrix, or hygroscopic salts impregnated in the matrix (Sahlot and Riffat, 2016). Materials such as vermiculite, pillar layered silica, silica gel, zeolite, expanded graphite, and carbon fibre are used as host materials because of the porosity feature (Miao et al., 2021, Wu and Wang, 2015, Zondag et al., 2013). As the host matrix, vermiculite

has been confirmed with slowdown sorption dynamics and low regeneration temperature (50–80 °C) (Aydin et al., 2015), allowing the reaction process to be more easily controlled, and supplying the stored energy when it is necessary (Muiambo, 2015). For instance, Casey et al. (2015) found vermiculite-CaCl₂ was a promising candidate for open THS systems, which exhibited high heat storage capability and rapid mass uptake at higher relative humidity levels. The characterisation analysis conducted by Jarimi et al. (2017) demonstrated the feasibility of using the vermiculite-based composite adsorbents in THS systems. The THS system is still under the research and development stage, which requires more studies on the innovative composite adsorbents and reactor designs (Shen et al., 2021).

This paper proposes a *Vermiculite-based THS System* (VS-THS). It provides an energy-efficient solution with a comfortable living condition for building space heating and dehumidification, involving an open-air loop operating at the atmospheric pressure without pressure fluctuation, which is safe to use in domestic applications. Unlike the vacuum-sealed system, the open-air loop THS system does not require pressure vessels and other associated complexity. A novel thermochemical reactor is incorporated in the proposed system, which is a patented ChainStore panel (patents CN201911077177.0 and CN201921903640.8 relate to the ChainStore). As shown in Figure 1, the unique ChainStore uses a metal mesh storage sheet, and the individual pocketed design enhances the heat and mass transfer performance. The composite adsorbent materials are accommodated in the storage sheet, which is flexible with a large heat and mass transfer area. When using multiple layers of ChainStore arrangement, the first layer will absorb water faster. One benefit of the design of multi-layer sheets is that the duration of discharge can be extended. As the water absorption of the first layer material increases, more moisture air will pass through the first layer material. At this time, the water absorption rate and reaction rate of the subsequent sheets will gradually

increase. This ensures that the heat release rate of the system can remain substantially constant throughout the discharging cycle. In the test, due to the airflow rate that has been set, the moist air is not completely absorbed by the first layer material. Also, because of the structure of the special columns of the ChainStore arrangement, the seams between each column of material are more breathable, thus allowing more moisture to pass through.

The flexible panel design of the ChainStore arrangement is extendable depending on the heating load for different buildings. The proposed system uses environmental-friendly, safe, and high-density vermiculite-based composite adsorbent and water vapour as the working fluid. In operation, thermal energy is stored when solar heat is used to dehydrate the composite adsorbent, releasing water vapour to the ambient environment. During the discharging process, humid air is circulated through the dehydrated composite adsorbent, and exothermic moisture adsorption occurs, producing warm and dry air for space heating. The system size can be tailored depending on the required period of heating autonomy. Moreover, based on basic materials and fabrication process, the VS-THS potentially offers low cost.

In this paper, the feasibility of the proposed VS-THS is examined through the experimental investigation of a laboratory prototype. The system design and construction will be briefly described in the next section. Then, as the main part, the laboratory tests will be introduced in detail, including the selection and preparation of THS composite materials, the construction of the experimental rig, the experimental procedure, and the analysis of the results.

2 SYSTEM DESIGN AND CONSTRUCTION

The whole project targets the overall solution for domestic heating storage system, aiming to reduce the electricity or gas consumption. Figure 2 presents the schematic



Figure 1 ChainStore sheets filled with adsorbent heat storage materials.

diagram of the proposed VS-THS in a residential building. The system is powered by a solar PV panel and can be integrated into the domestic space heating system. The solar PV panel provides power for the coil heater and the humidifier in the VS-THS. During the charging process, the VS-THS stores solar energy in the form of chemical bonds. In the discharging process, the solar PV panel powers the humidifier to release the previously stored solar energy for space heating.

The main structure of the VS-THS is an adsorbent heat storage unit. There are layers of ChainStore sheets placed parallel in the adsorbent heat storage unit. ChainStore sheets are flat bags made of metal mesh and filled with adsorbent thermochemical heat storage composite. For the selection of composite materials, the THS materials with higher energy density and lower regeneration temperature will be optimal. In the study, TA Instruments SDT-Q600 has been used for TGA measurements to analyse the energy density of the TES composites. The transitions and reactions of the materials were measured from ambient temperature to 150 °C under airflow. Measurements were performed at a rate of 10 °C/min over a temperature range from ambient to 150 °C using

samples of fully wet THS material (RH>95%). The results of energy density and regeneration temperature of the THS composites have been shown in Table 1. According to the results, compared with other composite materials, the vermiculite-based adsorbent material impregnated with MgSO₄ and CaCl₂ has been selected as the THS composite in our following experiment because of its low regeneration temperature (63 °C) and high energy storage density (1752.4 kJ/kg, 253.8 kWh/m³).

Two fans placed on the inlet and outlet of the unit are used for driving the air flowing through the unit. A coil heater and a humidifier are placed on the inlet ahead of the fan. In the charging process (or saying regeneration process), the heater is used for heating up the inlet air. The hot air dries the composite in the ChainStore sheets, so the heat energy is stored in the composite as thermochemical energy. During the discharge process (or saying reaction process), the humidifier is used to humidify the inlet air, and the moist air is propelled through the ChainStore sheets perpendicularly. A chemical exothermic reaction is targeted when the moisture contacts the composite material in the ChainStore sheets. Then the previously-stored thermochemical energy is released.

VERMICULITE-BASED THS COMPOSITE	ENERGY DENSITY, kJ/kg	BULK DENSITY, kg/m ³	ENERGY DENSITY, kWh/m ³	REGENERATION TEMPERATURE, °C
V-MgSO ₄ -CaCl ₂	1758.27	515.6	253.8	63
V-MgSO ₄ -LiNO ₃	1000.8	652.9	183.0	81.7
V-MgSO ₄ -LiCl	990.2	334.1	92.6	74.7
V-CaCl ₂ -LiCl	856.4	396.7	95.1	79
V-MgSO ₄ -LiNO ₃ -MgCl ₂	748.6	263.7	55.3	71.7

Table 1 Vermiculite-based THS composite energy density and regeneration temperature analysed by SDT-Q600 (Jarimi et al. 2017).

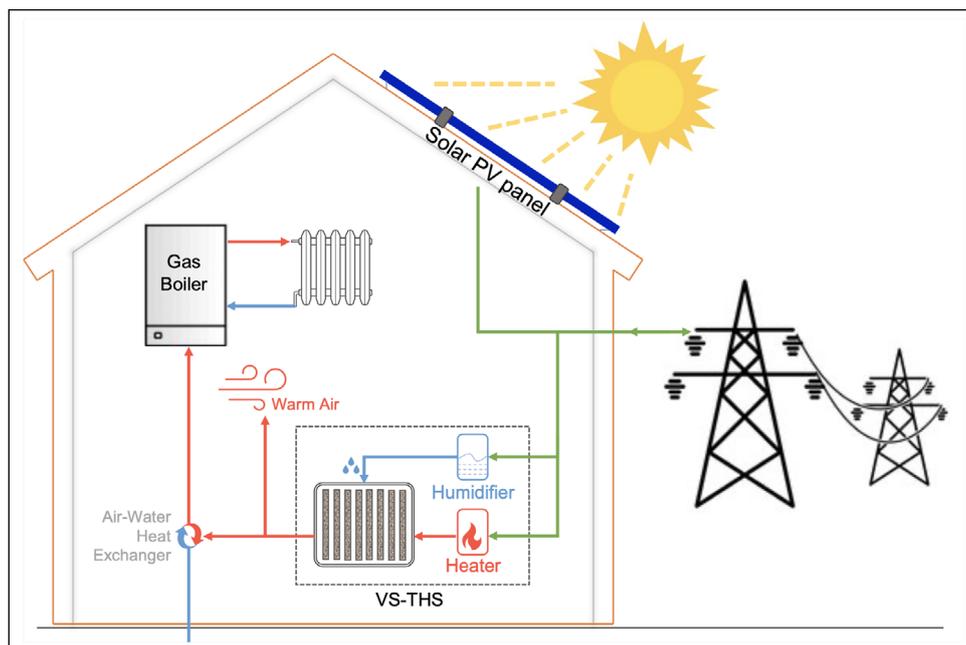


Figure 2 The diagram of the solar-powered THS system for space heating in the simulated domestic house.

This design matches the gap between the energy demand and requirements. When the sun is sufficient, the demand for space heating is low, a large amount of solar energy is available to be stored into the system and fed back to the grid when leftover. When sunlight is not enough, the demand for space heating increases. The remaining sunlight is usually enough to drive the humidifier. If solar energy is very low, the energy storage system can still be powered by the grid.

The output of the VS-THS fits the common domestic space heating systems. It can be used to heat the air via a heat exchanger or to boost the input water temperature of gas boilers. Based on this design, the VS-THS is also a key part of the peak shaving system, which balances the load of the energy system, uses more clean energy, reduces carbon emissions and bills, and improve the overall energy efficiency of the entire energy system.

3 LABORATORY TEST

A laboratory prototype of the proposed VS-THS was constructed to examine the system feasibility from a practical point of view and to prove the rationality of the simulation results. In order to evaluate the performance of the VS-THS, an experimental rig was set up, and the thermochemical adsorption composite material is manually made.

3.1 PREPARATION OF VERMICULITE-BASED COMPOSITE

In this study, the thermochemical adsorption composite material is a salt hydrate mixture of MgSO_4 and CaCl_2 stabilised in the porous vermiculite matrix. These salts are highly hygroscopic and will likely dissolve without proper containment within a host matrix. To prepare the composite adsorbent, followed the method pioneered by *Gordeeva and Aristov (2012)* in composite materials, the most common method is impregnating the matrix material with an aqueous salt solution. In this study, in total 5 kg raw vermiculite was fully dried prior to the impregnation with salts solutions. *Figure 3* shows the photo of the mixed salt solution, which combines 10 kg of MgSO_4 saturated solution and 10 kg of CaCl_2 saturated solution. Because this compound mix resembles yogurt, it is different from most other mixes that people have used in THS materials before. The mixture is viscous rather than completely liquid when wet. This property makes it possible to increase the mechanical strength of vermiculite after mixing with vermiculite. The viscous solution then was mixed with the dried vermiculite. The vermiculite-based composite was stabilised at room condition for 48 hours and then was dried in an oven at $150\text{ }^\circ\text{C}$ for another continuous 48 hours. During the drying process, the composite was stirred every 12 hours to prevent compacting, and *Figure 4* shows the photos of



Figure 3 Saturated MgSO_4 - CaCl_2 solution.



Figure 4 Dried vermiculite based MgSO_4 - CaCl_2 composite.

the dried composite. *Figure 5* shows the SEM photos of the microstructure of the surface of the vermiculite-based composite after treatment using THS salts solutions.

3.2 EXPERIMENTAL SETUP

Figure 6 presents the schematic diagram of the test rig for discharging process. The main components are two DC fans allocated at the inlet and outlet respectively; a humidifier is used to provide moisture air in the discharging process; and a reactor chamber in which ChainStore sheets filled with the vermiculite-based composite impregnated with MgSO_4 and CaCl_2 were placed. In the chamber, the humid air was passed to flow perpendicularly through each ChainStore layer. The water absorption rate of each layer of the vertically parallel ChainStore panels is decreasing, which also ensures that the energy can be released gradually without releasing heat too quickly. One of the benefits of this parallel multi-layered sheet design is that it extends the discharge time. As the water absorption of the first sheet increases, more water vapour will pass through the first sheet, and the reaction of subsequent sheets will gradually increase. This ensures that the heat release rate of the system can remain substantially constant throughout the discharging cycle. In addition, at the set airflow rate,

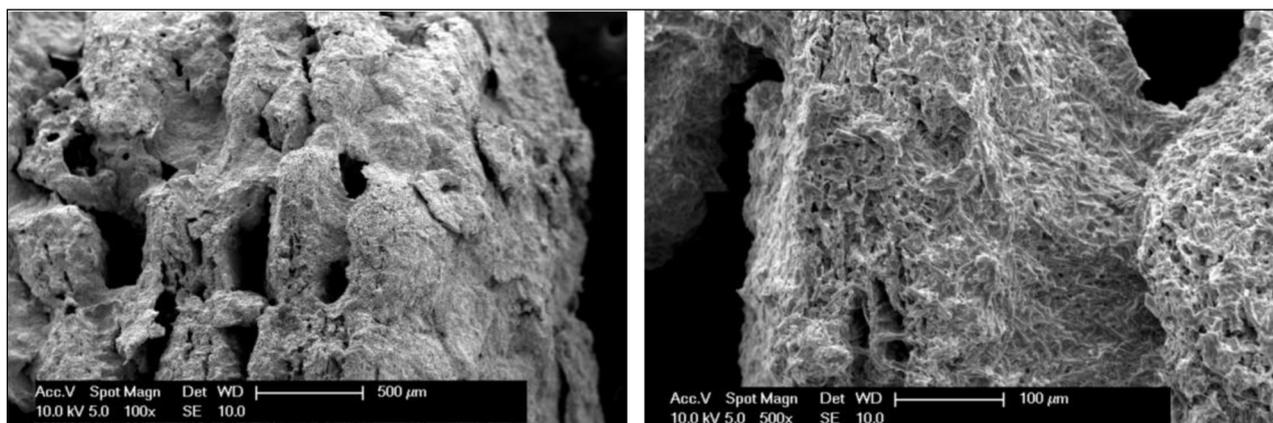


Figure 5 SEM photos of dried vermiculite based $\text{MgSO}_4\text{-CaCl}_2$ composite.

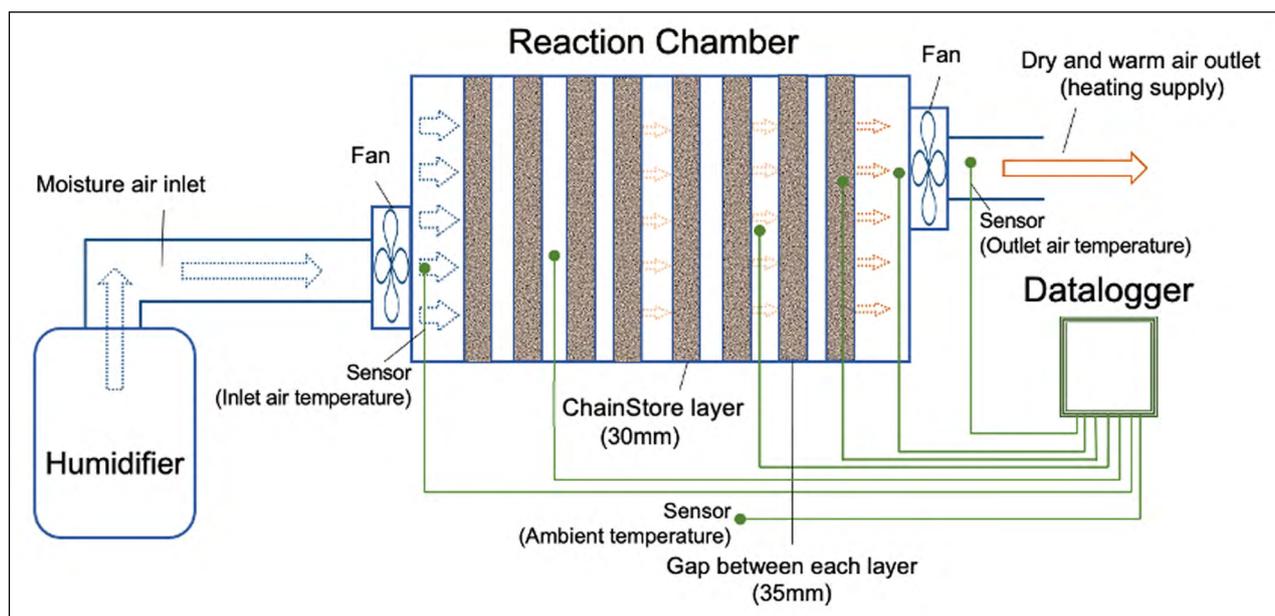


Figure 6 Schematic diagram of the test box.

the water vapour is not completely absorbed by the first layer of material. Moreover, because of the structure of this special column, the seams between each column of material are more breathable, which allows a lot of water vapour to pass through. This ensures that the reaction can proceed smoothly without being too fast.

During the discharging process, the humid air from the humidifier flows and passes perpendicularly through ChainStore sheets inside the reaction chamber, where the humid air reacts with the composite adsorbent. Consequently, the composite releases the stored heat, and then dried and warm air is supplied for indoor space heating. The discharging process can be described as follows:

Discharging process:

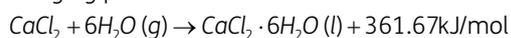


Figure 7 shows the photo of the built test rig, and the reaction chamber has an overall volume of 0.2 m^3

(400 mm in width, 500 mm in height and 1000 mm in length). A 50 mm thickness Kingspan insulation board was used to cover the external of the test box for thermal insulation. In terms of the two DC fans, the airflow rate was maintained at 1.34 m/s constantly during the discharging process.

Inside the reaction chamber, in total, eight ChainStore sheets were placed vertically, as shown in **Figure 8**. A ChainStore sheet is a flexible and thin structure with a thickness of 30 mm, which is conveniently stored in large rolls. The metal mesh cover allows efficient moisture transfer with little pressure drop and very good heat and mass transfer in operation. The total weight of the dried composite used in the reaction chamber was 7 kg (about 0.014 m^3). The thickness of each sheet was 3 cm, and there was a 3.5 cm gap between each ChainStore sheet. This vertical arrangement of ChainStore sheets allows excellent airflow movement and effectively reduces the issue of vermiculite-based composites compacting after a number of charging and discharging cycles.

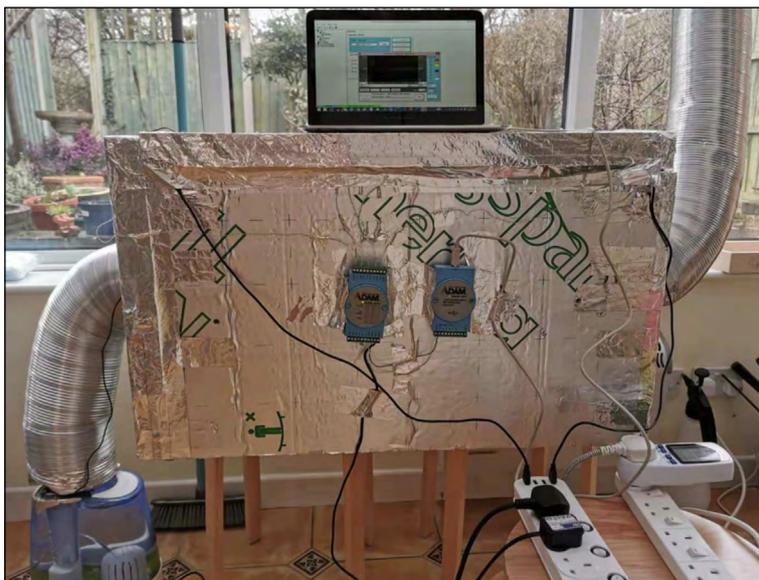


Figure 7 Photo of the test box.



Figure 8 ChainStore sheets with vermiculite-based composite.

Two sensors for monitoring the relative humidity level of the air were placed at the inlet and outlet, respectively, as seen in [Figure 9](#). The time is recorded every second. Seven sensors were placed inside the reaction chamber to record the temperature variations at different locations, and the recording time was set at every one second. Main measurement instruments with their respective accuracies are listed in [Table 2](#).

Two discharging experiments have been tested using the VS-THS ([Figures 6-9](#)). In the first discharging experiment (TEST 1), the ChainStore sheets are removable and can be replaced easily. In the 2nd experiment (TEST 2), the ChainStore sheets were sealed with the reaction chamber for better airtight. The airflow rate, relative humidity level and the experiment period were kept the same in the two-cycle experiments.

Since the goal of the experiment was to verify the feasibility of the discharging process, the ChainStore arrangement was prepared for fully charging before each test. In the charging process, each layer of the ChainStore was placed in an oven at 150 °C for 4 hours to dry

completely, and cooled to room temperature in a sealed container before each discharging process.

3.3 RESULTS AND ANALYSIS

All ChainStore sheets were completely dried in the oven at 150 °C, then sealed in the storage box and cooled down to room temperature at 20 °C before the discharging process. The entire discharging process was recorded for 6 hours. In this study, two tests of the discharging process were conducted and evaluated.

[Figure 10](#) present the results of the air humidity at the inlet and outlet during the two tests of the discharging process. As seen, the air inlet relative humidity level was kept at about 90% for more than 6 hours in the two tests discharging process. For the outlet air relative humidity level in TEST 1 experiment, it was approximately 28% at the end of the test; while in the TEST 2 experiment, the relative humidity level was less than 20% at the beginning and was gradually increased to 28% at the end of the test cycle.

[Figure 11](#) reports the results of temperature variation during the discharging process for two tests. According

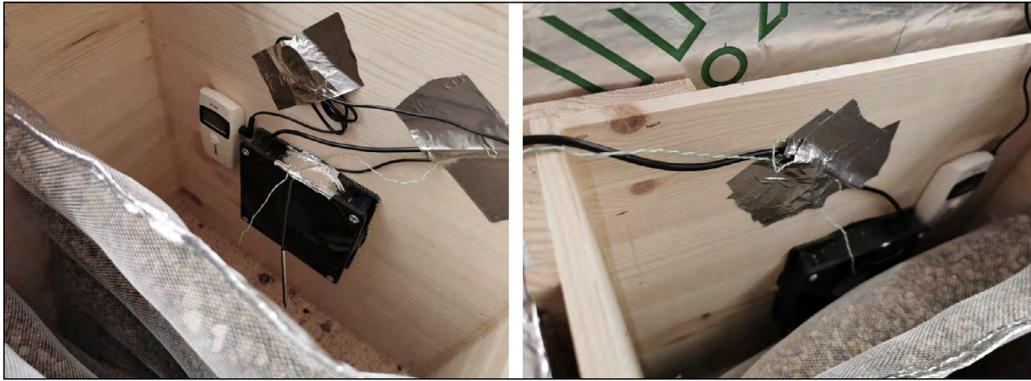


Figure 9 Photos of two fans with two humidity sensors at inlet and outlet.

DEVICE	MEASUREMENT RANGE	ACCURACY
RS K-type thermocouple probe	0–1100 °C	±0.75%
Sensirion EK-H4 humidity sensor	–40 to +125 °C 0–100% RH	±0.75% ±2%
Testo thermo-anemometer 405i	0–30 m/s	±5%

Table 2 Specifications of measurement instruments.

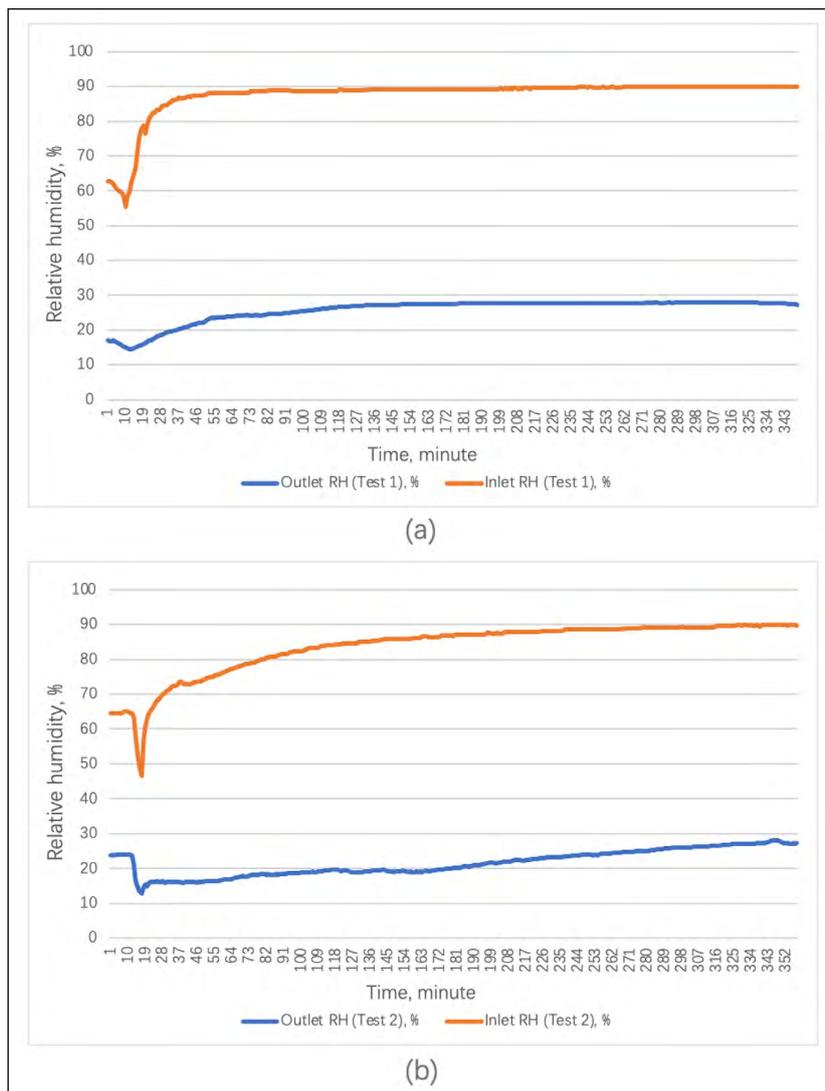


Figure 10 Inlet and Outlet air relative humidity (RH) level in (a) TEST 1 and (b) TEST 2.

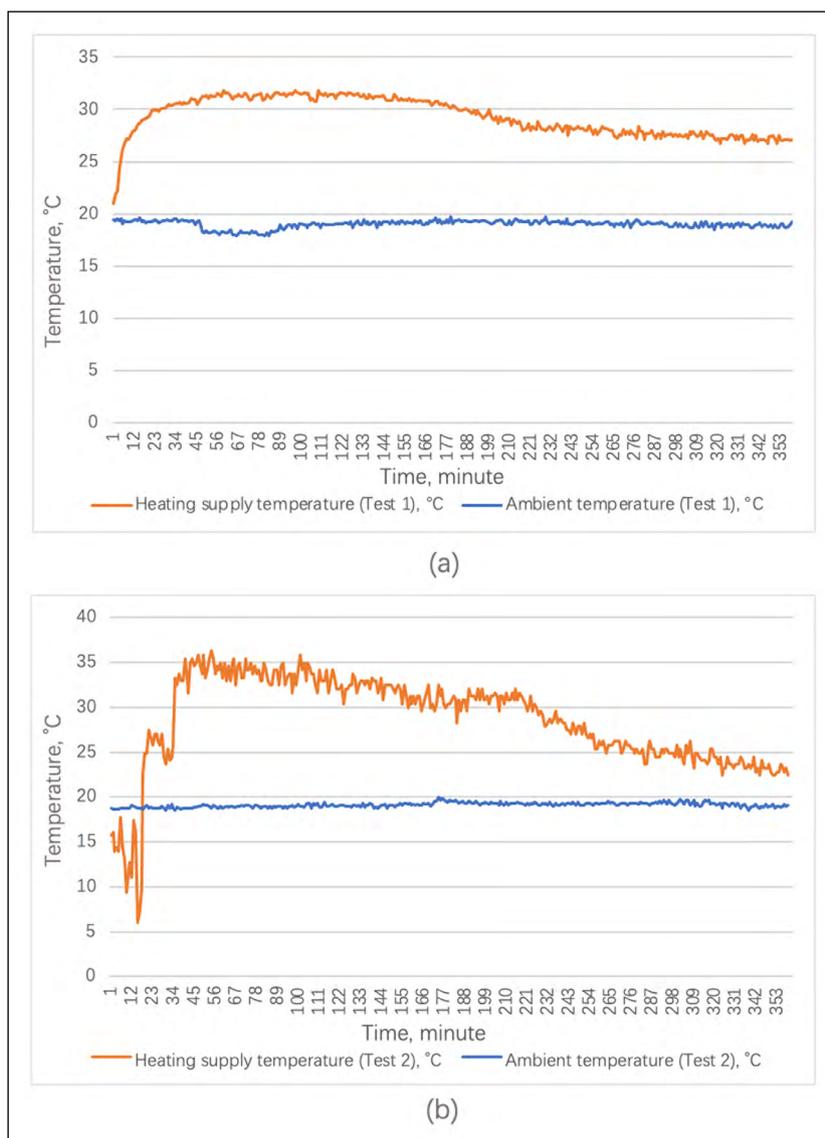


Figure 11 Supply heating temperature and ambient air temperature in (a) TEST 1 and (b) TEST 2.

to the obtained results, in Test 1 (see Figure 11 (a)), the highest supply air temperature was 32.04 °C, which was achieved at 91 minutes. Overall, the supply air temperature stayed above 25 °C for about 5 hours and 30 minutes. In Test 2 (see Figure 11 (b)), the highest supply air temperature was 37.6 °C and the outlet air temperature stayed above 25 °C for approximately 4 hours, in which approximately 3 hours the temperature was above 30 °C. The results of both experiments showed the same trend. When the system was activated, the outlet temperature (that is, the heating supply temperature) quickly reached over 30 °C and stayed for about 3 hours. It raised the ambient temperature by more than 10 °C. This result achieves our experimental goal. It demonstrates the good feasibility of the VS-THS in domestic buildings.

It can be seen that TEST 2 had a better performance on increasing the temperature of the airflow and obtained a higher heating supply temperature. This may be because of the better airtightness of ChainStore sheets in TEST 2.

After the first test of discharging process, we found that the relative humidity of the air at the outlet was higher than expected. Therefore, before the second test, the ChainStore sheets were refined by tightly sealing to the reaction chamber with a reducing in-between gap, which prevented incoming humid airflow from leaking from the reactor and thus enhanced reaction between the humid air and the composites in the ChainStore sheets.

The heating supply temperature curve in Figure 11 (b) fluctuates greatly, which may be due to the slight increase in airflow resistance after the improvement of ChainStore sheets and the slight decrease in the ventilation rate. Therefore, the sensor at the outlet was more susceptible to the disturbance by the ambient airflow. But overall, the trend of the supplied heating temperature changes remained the same.

In terms of the energy calculation, equation (1) is used to calculate the total heating energy supply:

$$Q_h = m_o \times C_o \times \Delta T \quad (1)$$

Where,

- Q_h = heat flow rate, [W]
- m_o = mass flow rate, [kg/s]
- C_o = specific heat capacity, [kJ/(kg·°C)]
- ΔT = temperature difference, [°C]

The specific heat capacity (C_o) of air is 1.006 kJ/(kg·°C). The airflow rate was 1.34 m/s during the testing. The diameter of the fan was 0.12 m. 5 hours experiment period was considered in the calculation. The total heating supply energy is the sum of the instantaneous heat flow rates. For TEST 1, the total released energy is 1.2 kWh, while 1.57 kWh of thermal energy was generated through the discharging process in TEST 2.

Taking the input power of the system into consideration, the coefficient of performance (COP) is defined as the ratio of the useful heat supply for space heating to the required input work required.

$$COP = \frac{Q}{W} \quad (2)$$

Where,

- COP = coefficient of performance
- Q = useful heat supply, [kWh]
- W = work required energy input, [kWh]

In the discharging process, the power input for the humidifier is 24.1 W, and for the DC fan is 6 W. The total working power input is 30.1W. Based on the results, the supply air temperature stayed above 20 °C for more than 5 hours for both tests, which were regarded as the useful heating supply period. Therefore, the COP for TEST 1 and TEST 2 are 7.9 and 10.4, respectively.

In TEST 1 and TEST 2 experiments, the humidity level changes has been observed. In this study, the discharge performance also needs to be evaluated by the water adsorption performance of the composite, which represents the change of air humidity throughout the reaction process in the reaction chamber (i.e., $\omega_{inlet} - \omega_{outlet}$). Thermophysical properties of the moist air are determined based on the measured air temperature and relative humidity by referring to equations 3–6 (Tsilingiris, 2008)

$$\ln \frac{P_{ws}}{P_c} = \frac{T_c}{T} \times (a_1 \times \vartheta + a_2 \times \vartheta^{1.5} + a_3 \times \vartheta^3 + a_4 \times \vartheta^{3.5} + a_5 \times \vartheta^4 + a_6 \times \vartheta^{7.5}) \quad (3)$$

$$\vartheta = \left(1 - \frac{T}{T_c} \right) \quad (4)$$

$$P_w = RH \times \frac{P_{ws}}{100} \quad (5)$$

$$\omega = 621.97 \frac{P_w}{P - P_w} \quad (6)$$

Where:

- P_{ws} = saturated water vapor pressure, [Mpa]
- P_c = critical pressure equal to 22.064 Mpa
- T_c is critical temperature equal to 647.096 K
- $a_1 = -7.85951783$, $a_2 = 1.84408259$, $a_3 = -11.7866497$, $a_4 = 22.6807411$, $a_5 = -15.9618719$, $a_6 = 1.80122502$.
- T = temperature, [K]
- RH = Air relative humidity, [%]
- P_w = Partial pressure of water vapour in the air, [Mpa]
- ω = Air humidity ratio, [kg/kg_{air}]
- P = Atmospheric pressure of moist air, [Mpa]

Since the reaction was a water adsorption reaction, the air at the outlet should be dehydrated and dried. Figure 12 shows the changes in humidity ratio and the reduction in moisture content for the inlet and outlet air in the two experiments. The moisture content of the outlet air humidity in both Figure 12 (a) and (b) was reduced to around 0.006 kg/kg, compared to the air inlet humidity of 0.012 kg/kg. This provides a relatively comfortable humidity environment.

Based on Equations 3–6, and Figure 12, we calculated the dehumidification capacity of the system. The two curves in Figure 13 represent the change in water removal over time in the two experiments. It can be seen that both lines are in the range of 40–60%, and the water reduction rate in the 2nd test is slightly higher than it is in the 1st test. The results prove the water adsorption performance of the vermiculate-based adsorbent, which could be a promising candidate for thermochemical energy storage applications.

4 CONCLUSIONS

In this study, a VS-THS was proposed to demonstrate the feasibility of storing heat energy and releasing the energy for later use for space heating and dehumidification in a residential dwelling. The system has innovative aspects over the existing THS systems, including high energy storage density at ambient temperature with an open-air loop operation; environmental-friendly novel vermiculite-based composite adsorbent; high-efficient reactor design with the patented ChainStore arrangement; low regeneration temperature, which can be met by a low-grade solar system in domestic applications, low space-demanding with a compact system design. In addition, the experimental investigation of the small-scale test rig showed that the reaction chamber with ChainStore arrangement could provide an efficient thermochemical reaction between the water vapour and the absorbent (i.e., vermiculite impregnated with $MgSO_4$ and $CaCl_2$). Based on the obtained results, the highest space heating supply temperature was 37.6 °C, and the total released heat is 1.57kWh. The COP of the entire system was 7.9–10.4. The findings verified the feasibility of the proposed VS-THS, and the composite of vermiculite impregnated with $MgSO_4$ and $CaCl_2$ could be a promising candidate for THS systems.

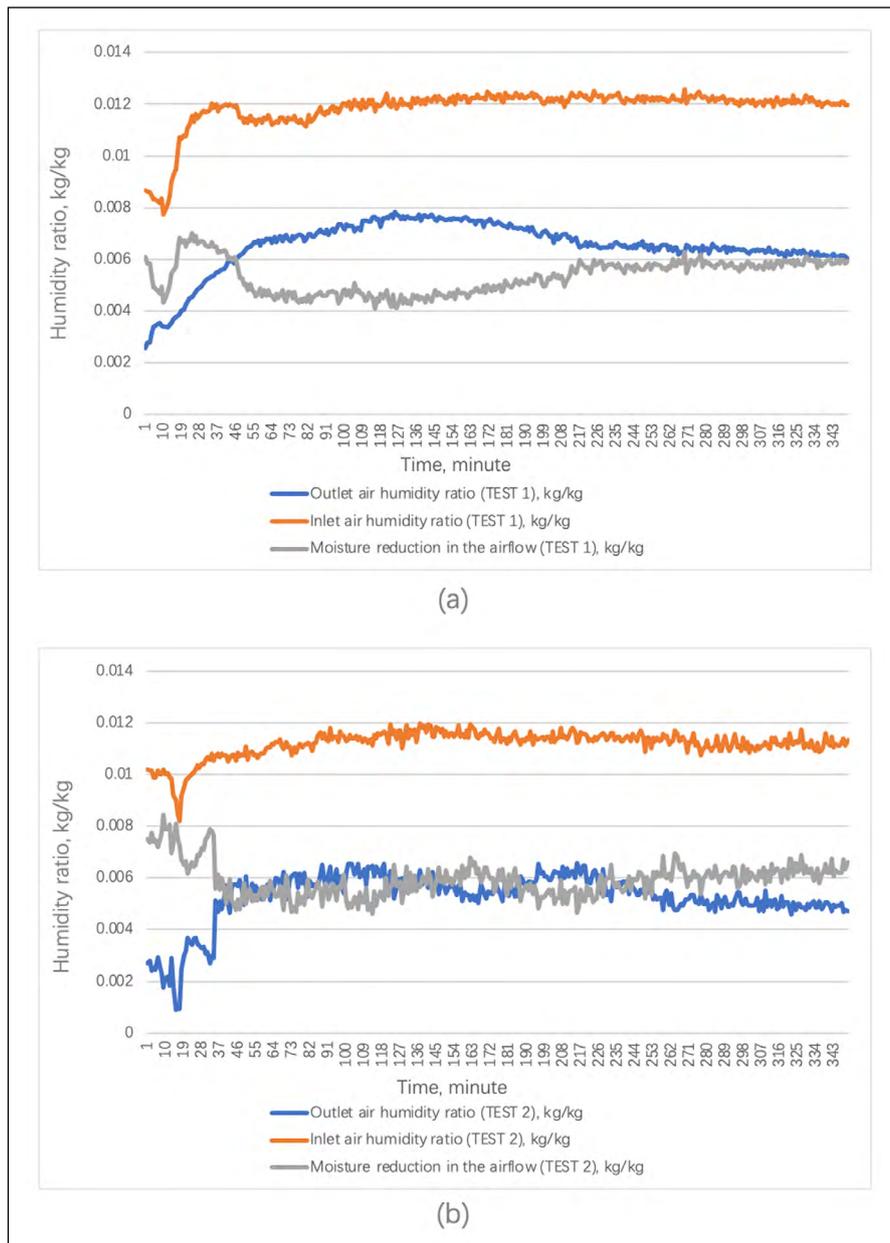


Figure 12 The water content at the inlet and outlet of (a) TEST 1 and (b) TEST 2 discharging process.

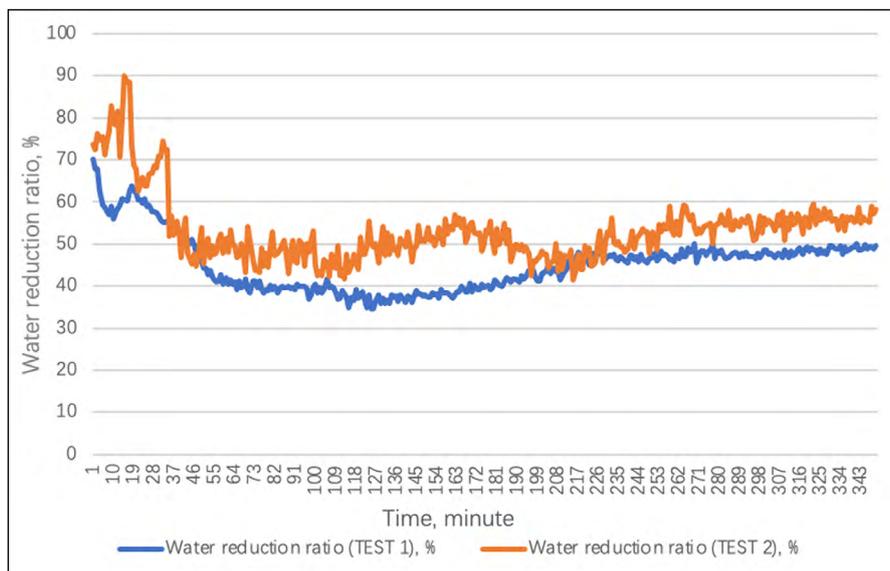


Figure 13 The water content reduction ratio in the experiments of two cycles of discharging process.

NOMENCLATURE

Q_h	Heat flow rate, W
C_p	Specific heat capacity, $\text{kJ kg}^{-1} \text{ }^\circ\text{C}^{-1}$
m_o	Mass flow rate, kg/s
ΔT	Temperature difference, $^\circ\text{C}$
COP	Coefficient of performance
Q	Useful heat supply, kWh
W	Work required energy input, kWh
P_{ws}	Saturated water vapor pressure, Mpa
P_c	Critical pressure equal to 22.064 Mpa
T_c	Critical temperature equal to 647.096 K
T	Temperature, K
RH	Air relative humidity, %
P_w	Partial pressure of water vapour in the air, Mpa
ω	Air humidity ratio, $\text{kg/kg}_{\text{air}}$
P	Atmospheric pressure of moist air, Mpa

SUBSCRIPTS

h	heat
a	air
ws	saturated water
w	water
c	critical
inlet	inlet air
outlet	outlet air

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COMPETING INTERESTS

The authors have no competing interests to declare.

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