Tyler Lewis Clean Energy Research Foundation

2018 Grant Recipients

Solar Heating, Nanoparticles for Solar Cells and Carbon Dioxide Conversion

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*Maximizing Passive Solar Heating in Canadian Homes Using a Solar Collection System

Motivation

Passive solar design can significantly reduce space heating requirements in buildings. A common passive design feature is large window areas (specifically south-facing) to increase space heating by passive solar gains. An issue that has been noted in some houses that have this feature is overheating of the spaces that contain the windows [see ***Figures 1*** and ***2***]. This issue of overheating causes window areas to be restricted to modest amounts in homes.

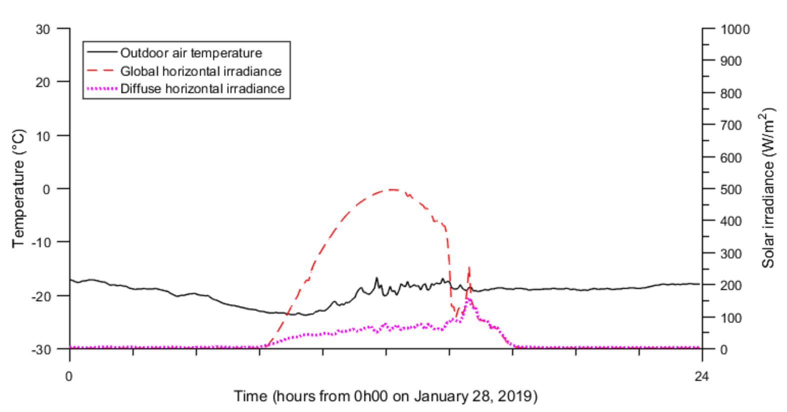


Figure 1: Outdoor air temperature and solar irradiance on January 28th, 2019 in Ottawa, ON (a sunny but cold day).

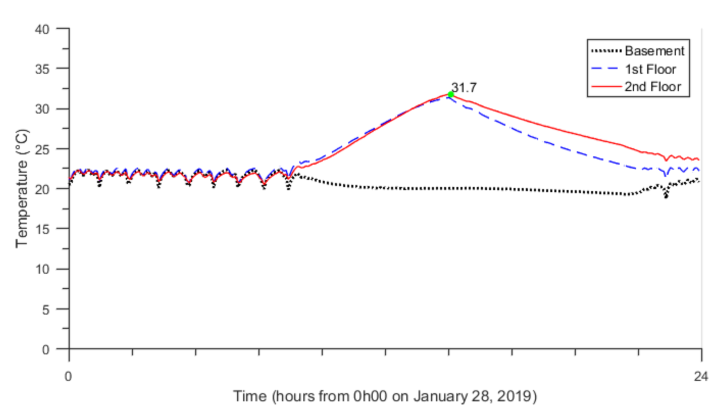


Figure 2: Temperatures inside a house in Ottawa on January 28th, 2019. The house has lots of south-facing window area (~20 m²).

Proposed Solution

Large areas of south-facing windows are used to optimize solar gains to offset heating demands. Cold water is circulated through a hydronic floor system to extract the excess thermal energy from these rooms and prevent overheating. A water-water heat pump is then used to transfer the extracted energy from the cold water storage to hot water storage, which can be used to provide hot water for DHW or space heating through the hydronic floors during periods of heating demand. Figure 3 shows this system operating in its cooling and heating modes.

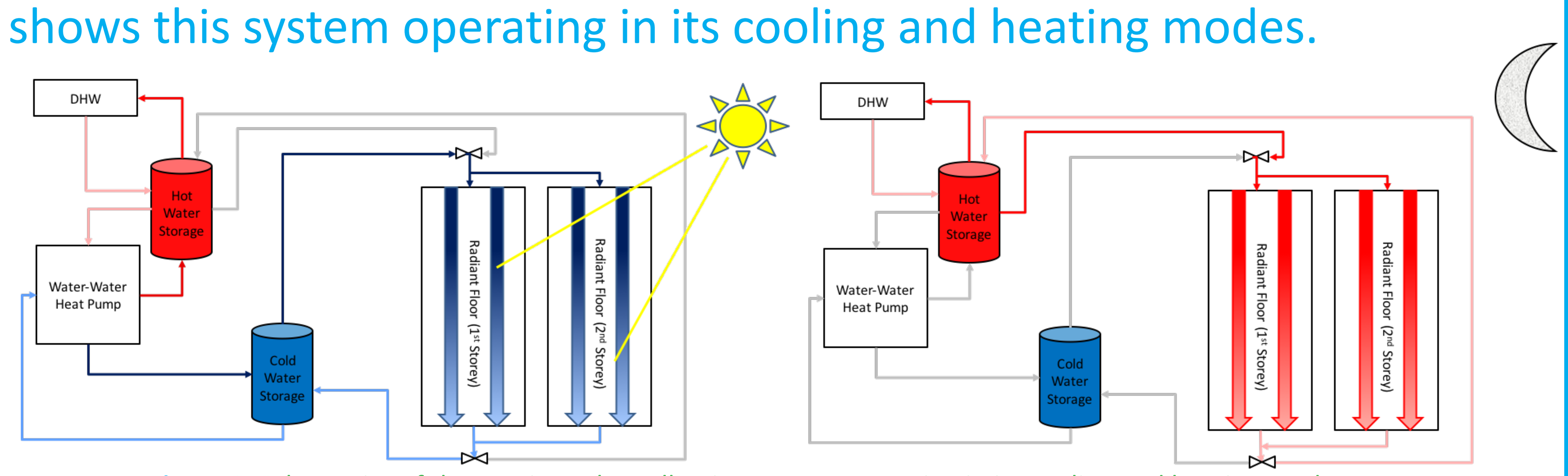


Figure 3: Schematics of the passive solar collection system operating in its cooling and heating modes.

Results

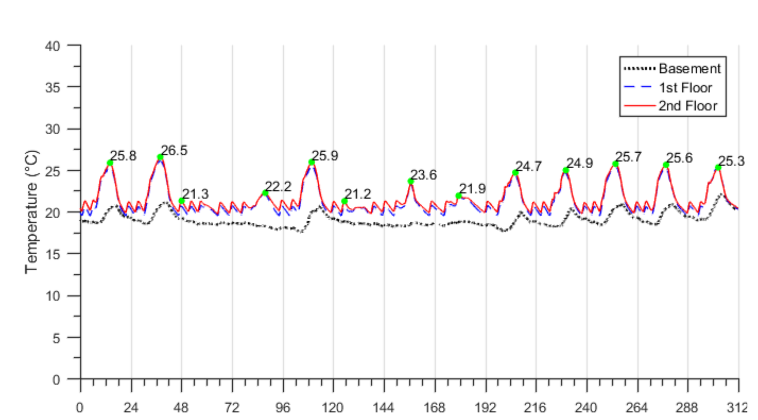


Figure 5: Indoor air temperatures in the same house as Figure 2 with the described floor cooling system operating to prevent overheating.

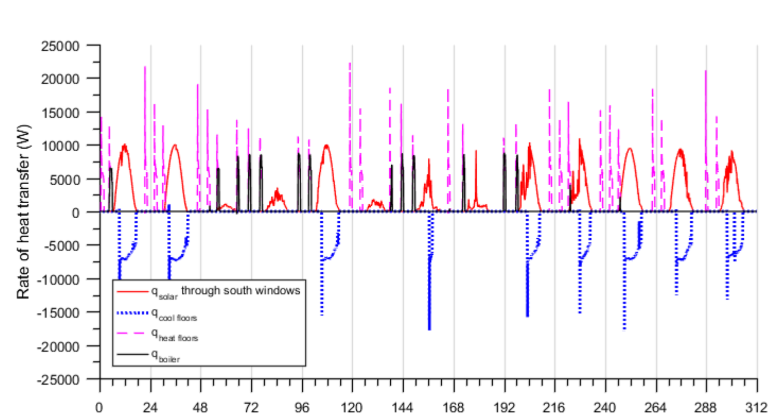


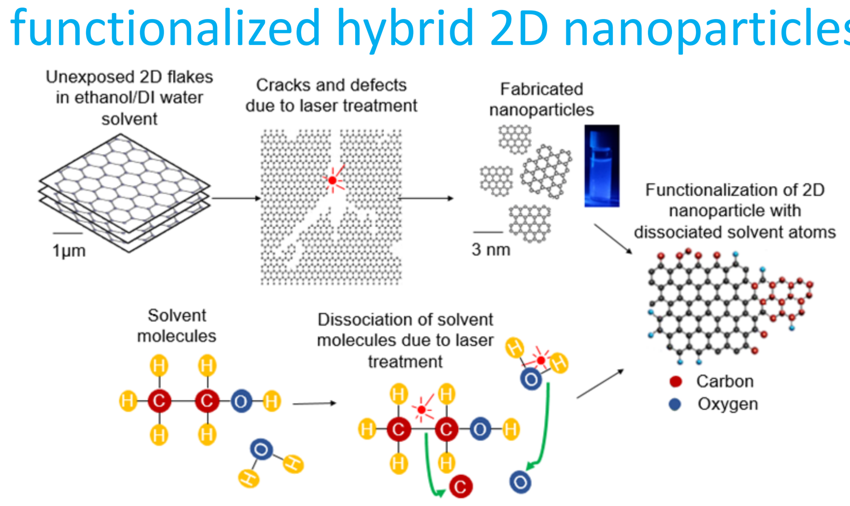
Figure 6: Heat transfer processes occurring in the house.

During these 13-days, 1810 MJ of solar energy was transmitted through the south-facing window area and 1412 MJ of energy was extracted by the floor cooling system. 64% of the active space heating demands during this period were able to be supplied by the stored energy (instead of from an electric boiler) in addition to the heating demands offset by the passive solar gains that remained in the living spaces.

†Fabrication of Novel Nanoparticles for Solar Cells and Greenhouse Gas Sensors

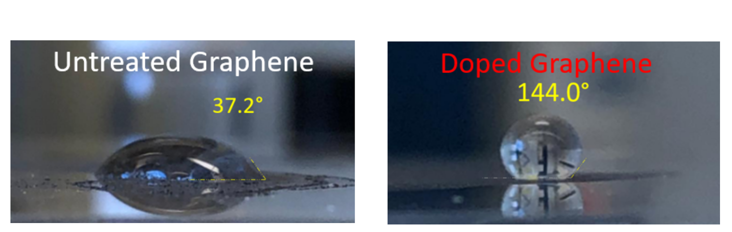
Fabrication of Doped 2D Nanoparticles and its Importance

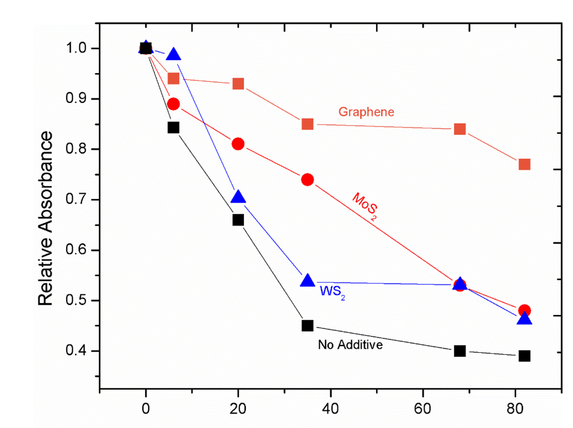
- Graphene, Molybdenum disulfide (MoS_2), and Tungsten disulfide (WS_2) have recently garnered significant attention due to their unique mechanical and optical properties.
- Doping or chemical functionalization of these 2D nanomaterials is of interest for many applications in sensing, biomedicine, tribology, photonics, and electro-catalysis, among others. Herein we implement them in solar cells to reduce moisture degradation.
- These techniques for fabricating and doping 2D nanosheets and smaller nanoparticles are relatively slow (in some cases requiring several days), often require dangerous chemicals and elevated temperatures, and their demonstration has been material-specific.
- As illustrated below, we introduce a novel laser-treatment technique in which we simultaneously reduce the bulk 2D nanosheets and flakes into a few nanometers particles and dissociate solvent molecules to bond with the edges of the freshly cleaved 2D sheets, in order to produce doped functionalized hybrid 2D nanoparticles.



Enhancing Solar Stability by Inserting 2D Nanoparticles as Additives

- The 2D nanoparticles hydrophobicity was assessed by examining the contact angle of the doped particles. Below the doped graphene before and after laser treatment is shown. The contact angle for doped graphene is found to be 144 deg indicating a higher hydrophobicity.
- The 2D nanoparticles were then inserted as a passivation and sacrificial layer to protect the solar cell film from moisture degradation.
- By inserting the samples in a chamber at 85% relative humidity and monitoring the degradation over an 82 hour span by measuring the optical absorbance of the solar cell film.
- The exciting results shown below, indicate an enhanced stability and lack of moisture degradation for the graphene particularly over the testing time span.





Impact and Future Work

- This is a major step towards commercialization of perovskite solar cells as the cell stability has been a bottle neck.
- Different dopants for the 2D particles are to be tested in an attempt to enhance the stability further.

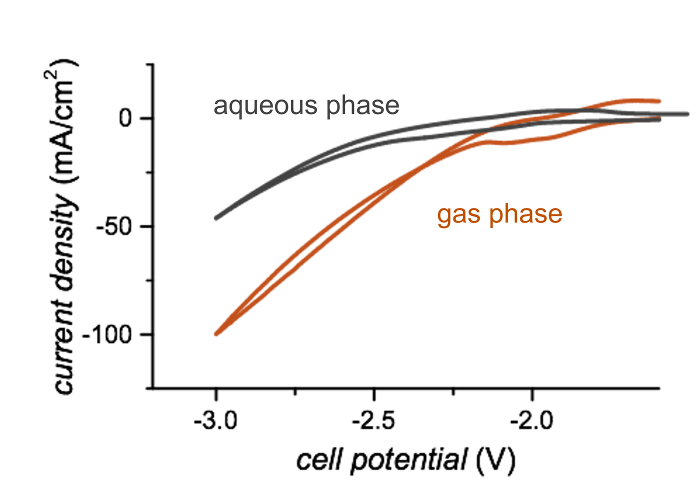
‡Electro-Catalytic CO_2 Conversion in Flow Cells

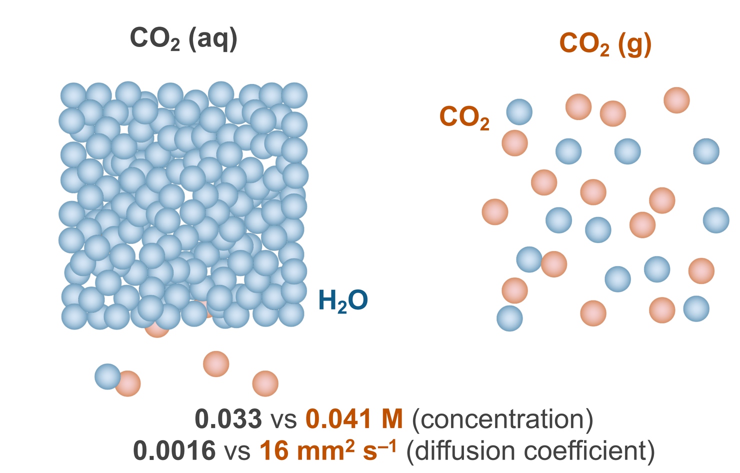
Electrolysis of CO_2

The electrochemical conversion of CO_2 provides an attractive platform to store inexpensive renewable electricity by converting a waste greenhouse gas into products of value. Electrolysis performance must demonstrate high current densities (>200 mA/cm²) that match present commercial water electrolyzers. However, most CO_2 electrocatalysts which are tested in aqueous solutions have low current densities or employ expensive ionic liquids.

Higher Current Densities Can Be Achieved in the Gas Phase

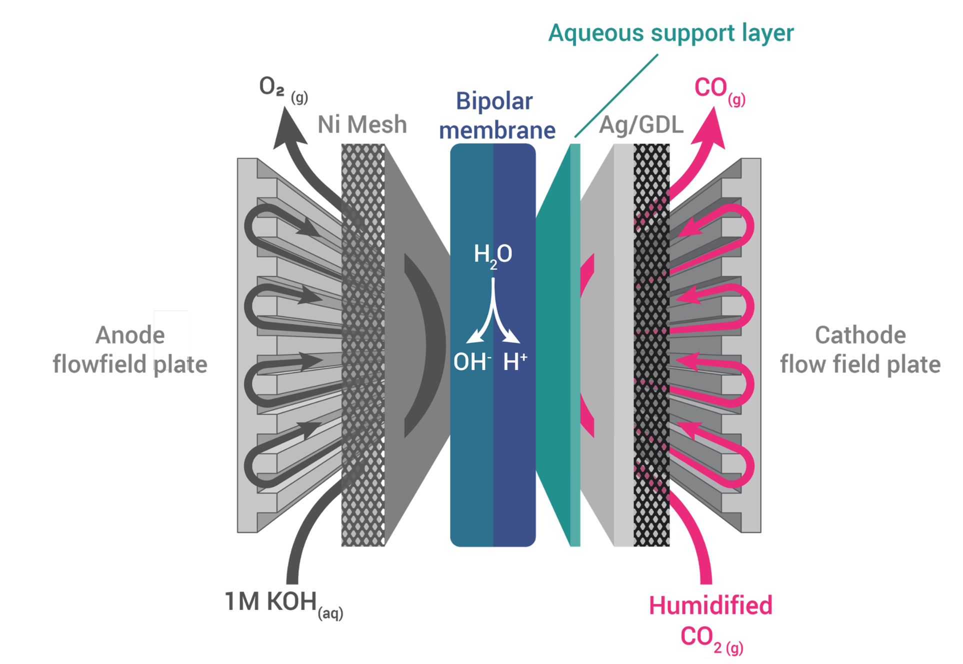
CO_2 is not very soluble in aqueous media, which limits the current densities that can be achieved. The concentration of CO_2 at 1 atm is 25% higher than be achieved with aqueous solutions. Additionally, the diffusion coefficient of gaseous CO_2 is 4 orders of magnitude greater than in liquid phase. Gas phase electrolysis therefore has the potential to increase mass transport and achieve higher current densities.





Our CO_2 to CO Bipolar Membrane Reactor

We have demonstrated high CO selectivities at high current densities in gas phase bipolar membrane-based flow cell architecture. Our flow cell architecture employs a bipolar membrane (BPM) which enables the use of efficient and earth-abundant anode catalysts (Ni mesh) that are stable in alkaline media and acid-stable cathodes for CO2 reduction (e.g. Ag). Water dissociates into H+ and OH– ions at the interface of the cation (CEL) and anion exchange layers (AEL) under reverse bias. The H+ migrate through the CEL to reduce CO2 at the cathode and, similarly, OH– ions are transported through the AEL for water oxidation at the anode.



References:
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Li, Y.C; Zhou, D.; Yan, Z.; Goncalves, R.H.; Salvatore, D. A.; Berlinguette , C.P.; Mallouk, T.E., *ACS Energy Lett*, 2016