Project Title:

ENRTF ID: 134-E

Energy Storage Panels for Home and Office Upgrade

Category: E. Air Quality, Climate Change, and Renewable Energy

Total Project Budget: $ 687,746

Proposed Project Time Period for the Funding Requested: 3 years, July 2017 - June 2020

Summary:

Proposed: Wall panel for home and office energy efficiency upgrade, holding energy storage material to exchange heat with the room during daily cycle. Novelty: fabrication using plate and roll-to-roll technology.

Name: Terrence Simon

Sponsoring Organization: U of MN

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Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

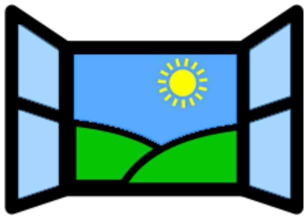
Shown is a room with panel installed on one wall, heated by the sun or room heater and cooled to heat the room in the evening. Embossed articles of similar geometry are also shown to indicate the capability of the lab.

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

_____ Extent of Impact _____ Innovation _____ Scientific/Tech Basis _____ Urgency

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

I. PROJECT STATEMENT



An energy storage panel for home and office heating/cooling efficiency upgrade that uses energy storage material is proposed. It absorbs heat in a warm room and returns it when the room cools. Novelty lies in its fabrication using plate and roll-to-roll embossing technology to encase the energy storage medium in cavities formed within polymer panels. The panels are installed within homes and offices in a way that is similar to putting up decorative wall panels. They are thin and pliable and can be applied with ease. We estimate that a single 4x4 meter wall panel will store or liberate the equivalent of five kilowatt-hours of electric power with each daily cycle.

The state of Minnesota consumes 4.55 million MW-hrs. of electric power and 12.97 billion m^3 of natural gas each year summing to a cost of one trillion dollars per year for home and office heating and cooling. Since it is far more effective to reduce energy use than to develop new sources, we propose this novel method for indoor thermal management. Room comfort requires thermal control to within a narrow temperature band. It can be done using energy storage material that transitions in phase, such as liquid to solid, over a narrow temperature range either absorbing or liberating heat. As such, this material is perfect for building comfort control. Chemists have identified many material types (called phase change materials); some store and release heat at comfortable living space temperatures. In the proposed work, we select one and implement it into a novel wall panel made with modern polymer fabrication techniques to contain the material and to enhance heat exchange between the storage material and the room. The proposed uses advanced manufacturing to eliminate deficiencies of previous energy storage methods with similar objectives. Modern polymer processing steps, such as plate embossing and roll-to-roll embossing, have developed to the point that wall panels containing energy storage material can be rapidly and inexpensively fabricated. The panels are internally-finned polymer sheets. The fins improve heat transfer to and from the storage material and form cavities to contain the material. Success will be with fabrication precision, speed and low cost afforded by the technique. Further enhancement of heat transfer will be by fabrication with embedded nanofibers, which this embossing technique facilitates. For this fabrication, we draw upon the considerable expertise developed in our lab applied to a myriad of applications, such as cooling of electronics. Previous studies have shown that homes with walls made of such energy storage material impregnated into plasterboard receive a 15% reduction in energy use. We expect to surpass this by increasing the volume of such material in the wall while maintaining the total volume. Also, thermal transport between the storage material and the room will be enhanced over plasterboard and other previous designs by using our unique manufacturing methods to put highly conductive carbon nanotubes into the energy storage panels.
Salient features of this proposal include:

- Energy storage in wall panels to absorb energy when room is warm to retrieve when room cools
- Comfort is enhanced by panel by making room temperature more uniform in time and space
- Energy leveling allows solar heating by day and reduced room active heating by night
- Household energy leveling allows less daytime air conditioning; energy leveling the power grid
- Panel design allows easy energy-related upgrade to present homes and offices
- Enhanced performance and reduced cost are allowed by use of our modern fabrication technique
- Worth of the energy storage panels increases when time-of-day energy rate pricing is applied

II. PROJECT ACTIVITIES AND OUTCOMES

We will develop a rapid and inexpensive fabrication method for energy-storage-material encased wall panels having embedded nanofibers in the storage material for enhanced heat transfer. The panel is designed for maximum thermal transfer and storage efficiency. At each phase we will display a fabricated wall segment for performance testing and review for market acceptability. Novel developments in polymer fabrication are employed. The design applies our expertise on fluid mechanics, heat transfer, stresses and deflections as well as fabrication of embossed polymer articles such as applied to our recently-completed, patented electronics cooling heat sink module. The project will document project costs to show market competitiveness.

Activity 1: *Demonstration of panel segment* **Budget: $207,000**

We 1). conduct an exhaustive study of candidate energy storage materials for inclusion into polymer cavities specifically designed and fabricated for this application, 2). construct prototypes using the hot embossing fabrication technique, 3) demonstrate thermal transport effectiveness as enhanced with carbon nanotubes 4). discuss with potential customers.

Outcome: A working panel for measurement and market comments	**Completion Date**
1. Construct test wall segments fabricated with plate embossing technology	*April 30, 2018*
2. Demonstrate nanofibers for thermal enhancement	*June 30, 2018*

Activity 2: *Optimization with roll-to-roll fabrication* **Budget: $259,000**

Develop new rapid fabrication methods: roll-to-roll embossing for reduced cost and improved thermal performance by advanced designs for holding storage material with nanotubes for enhanced transport.

Outcome	**Completion Date**
1. Optimize system with roll-to-roll fabrication for reduced cost and greater flexibility	*June 30, 2019*
2. Cost estimates and market responses lead to revised system esthetics	*June 30, 2019*

Activity 3: *Continue refinement, demonstration with solar heating of room, investigation of incorporating internal heating/cooling, new prototype to demonstrate* **Budget: $221,746**

Continue improvement and demonstration in a home with solar flux to an interior energy storage wall panel. Extend design to include internal heating and cooling channels for use with heater or heat pump (A/C) units.

Outcome	**Completion Date**
1. A next-generation system with test room and solar heating	*Dec. 31, 2019*
2. A system with internal channels for through flow and demonstration with heat pump (A/C). Devise control strategies for use with time of day electrical rates	*June 30, 2020*

III. PROJECT STRATEGY

A. Project Team/Partners

Professor Simon: Ernst G. Eckert Professor of Mechanical Engineering at the University of Minnesota with expertise in fluid mechanics and heat transfer. Professor Simon will serve as the PI and project manager. He will be responsible for overseeing the project, all reports, and deliverables. He will be engaged in thermal fluids aspects of both the embossing fabrication and the design of the energy storage panel.

Professor Cui: Professor of Mechanical Engineering and an Affiliate Senior Member of the graduate faculty in the Department of Electrical and Computer Engineering at the University of Minnesota with expertise in advanced manufacturing and device design, especially with nanoparticles and nanotubes.

B. Project Impact and Long-Term Strategy

This proposed thermal storage wall panel will allow heating by day, perhaps by solar, and reduced space heating at night. It can be cooled or heated from room air when the price of electricity is lower and operate with reduced electricity use when the price of electricity is high. It could capitalize on time-of-day electrical pricing. Internal flow channels for use with a heater, heat pump (heating or air cooling unit) are included as final phase.

C. Timeline Requirements

The project will require 36 months to complete with milestones explained above.

2016 Detailed Project Budget

Project Title: Roll-to-Roll Wall Tape for Energy Saving

IV. TOTAL ENRTF REQUEST BUDGET: 3 Years

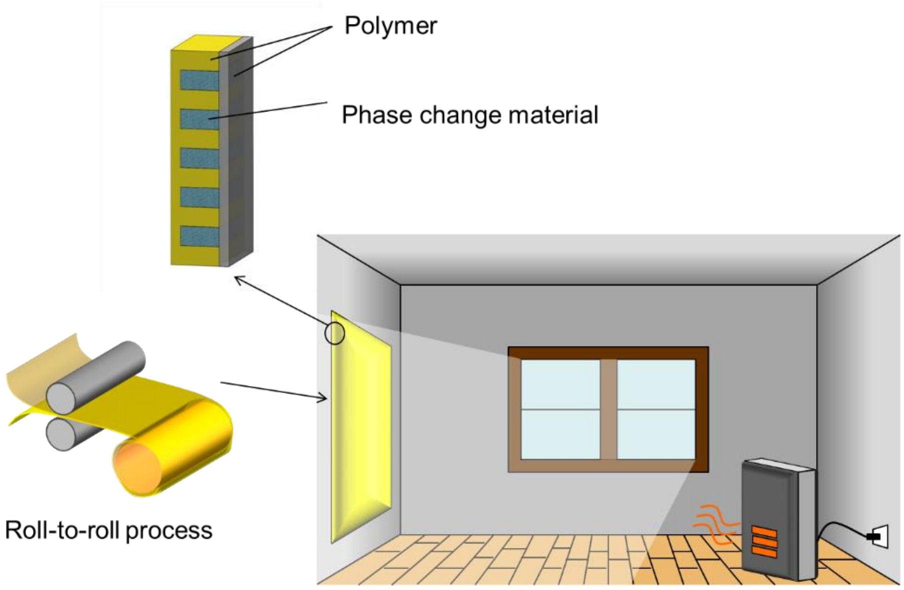
BUDGET ITEM	AMOUNT
Personnel:	
Dr. Terrence Simon PI (4.3 weeks (.11FTE) + fringe 33.8% fringe) for 3 years. 9 months appointment	$ 67,249.00
Dr. Tianhong Cui Co-PI (4.3 weeks (.11FTE) + fringe 33.8% fringe) for 3 years. 9 months appointment	$ 73,759.00
3 Graduate Research Assistants 50% FTE (fall & spring include 16.6% fringe plus $17.84/hour tuition, summer 16.6% fringe only) for 3 years	$ 393,738.00
Equipment/Tools/Supplies:	
Lab Supplies (Simon): Items for fabrication of the verification facility, thermocouples and reading instruments (as needed to supplement), raw materials for testing, thermal control unit, fans, controllers and ductwork.	$ 33,000.00
Scientific Services (Simon): User fees at Machine Shop at the University of Minnesota. 250hrs of shop service time and supplies for fabrication of the test chambers used to characterize the panels	$ 21,000.00
Lab Materials & Supplies (Cui): Purchase of polymer materials ($12,000), chemical reagents ($9,000), silicon wafers and glassware ($9,000), consumable supplies (standards and columns) for analytical instruments ($9,000), instrument maintenance and repair ($9,000)	$ 48,000.00
Scientific Services (Cui): User fees at Minnesota Nano Center and Characterization Facility at the University of Minnesota. The cost is $583 per month for two graduate research assistants for 3 years.	$ 42,000.00
Travel:	
Simon and Cui domestic travel (once a year): Domestic conference travels.	$ 9,000
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 687,746

V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period:	N/A	
Other State $ To Be Applied To Project During Project Period:	N/A	*Secured*
In-kind Services To Be Applied To Project During Project Period:	N/A	
Funding History: Active Heat Sink Technology, Air Cooling of Electronic Equipment, DARPA, $3,186,638, 3 years, 01/01/09-12/31/12.	$3,186,638	Secured
Remaining $ From Current ENRTF Appropriation:	N/A	

PI/PD: Terrence Simon and Tianhong Cui, University of Minnesota

Project Title: *Energy Storage Panels for Home and Office Upgrade*



Proposed: Energy storage panels for home and office energy efficiency upgrade (applied to an existing wall very simply and inexpensively)

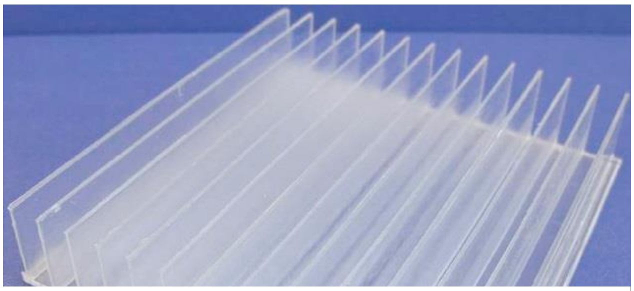
Right: Panel on one wall receiving daytime sun and room heating. Panel could cover an entire wall.

Upper left: A cut-away of the panel showing the polymer encasing the energy storage (phase change) material.

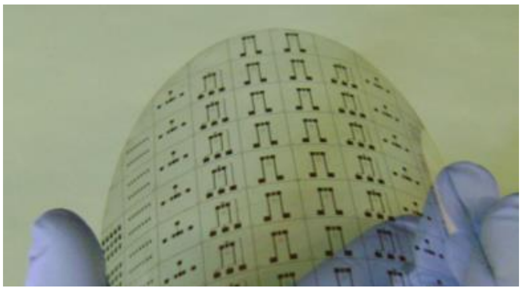
Lower left: A latter stage of the project will bring roll-to-roll embossing to replace plate embossing for cost reduction and speed of manufacturing.

No change is needed to existing energy saving features of the house, insulation from the outside on the walls and ceiling (as shown in cut-away view).

Previous Work on Polymer Manufacturing.



Polymer micro channels fabricated with hot, plate embossing (from previous project of Cui and Simon) in which research led to fabrication of very thin webs made by flow of polymer to the full width and length of the thin fins of this structure before cooling and setting.



Flexible polymer micro structures (from previous project of Cui and Simon)

The pliability of the panel fabricated similarly allows easy application to an existing wall -- like wall-papering

Project Title: *Energy Storage Panels for Home and Office Upgrade*

Project Manager Qualifications and Organization Description

Personnel:

Terrence Simon is the Ernst G. Eckert Professor of Mechanical Engineering at the University of Minnesota. He received his B.S. from Washington State University, his M.S. from the University of California at Berkeley and his Ph.D. from Stanford University (1980). His expertise lies in flow and heat transfer in steady and unsteady turbulent and transitional, single and two-phase flows. Applications include electronics cooling, gas turbines, Stirling engines, and energy storage. He is a Fellow of the Amer. Soc. of Mech. Engr. (ASME) and Vice-President of the International Centre for Heat and Mass Transfer. He is a recently retired Technical Editor of the ASME Journal of Heat Transfer. Professor Simon will serve as the PI and project manager. He will be responsible for overseeing the project, all reports, and deliverables. He will be engaged in thermal-fluids aspects of both the embossing fabrication and the design of the energy storage panel.

Tianhong Cui is currently a Professor of Mechanical Engineering and an Affiliate Senior Member of the graduate faculty in Department of Electrical and Computer Engineering at the University of Minnesota. He joined the faculty of the University of Minnesota in 2003. He was also a visiting professor at University of Freiburg in Germany in 2006. He is an international leading expert on micro devices, and micro-nano fabrication including molding of polymers and especially application of graphene and carbon nanotubes in sensors. He has more than 260 publications and 5 U.S. patents in the relevant area. As an editor-in-chief, he founded the first engineering journal of Nature Publishing Group titled *Microsystems & Nanoengineering*, and he is also responsible for another Nature Journal, *Light: Science & Applications*

Facilities:

The Mechanical Engineering Department at the University of Minnesota is nationally ranked in the top 15 programs by U.S. News and World Report. The University and Department have numerous resources available for the proposed work including: the 16th largest library collection in North America, the Supercomputing Institute, and a professionally operated Machine Shop.

Hot Embossing Machine

The design and characterization of the plate and roll-to-roll embossed wall panels proposed here will be performed in the Technology Integration and Advanced Nano/Microsystems Laboratory (TIAN Lab). The lab is equipped with state-of-the-art instrumentation and facilities to conduct the proposed research. TIAN Laboratory resources include a variety of fabrication and characterization equipment and tools, sufficient to design, fabricate, characterize and analyze the panel. The Minnesota Nano Center is also available for micro-scale characterization and processing.

The experimental verification will be done in the Heat Transfer Lab at University of Minnesota. It has been involved with thermal-fluid measurements over the last 75 years and one of the co-PIs has been a part of it for the last 36 years. The demonstration module will be designed with computational support, experiments on separate aspects of the design (light polymer flow in the chosen geometry) and testing of final panel designs. Verification test facilities will be constructed with the myriad of pumps, fans, ducts, heaters, thermocouples, reading instruments, and other standard heat transfer lab equipment available in our well-equipped heat transfer laboratory. We anticipate using these devices, as needed, and adding to the inventory with new minor supplies as needed.