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A Novel Modular Design Approach to "Thermal Capacity on Demand" in a Rapid Deployment Building Solutions:

Case Study of Smart-POD

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Abstract

Designed to address the challenges of a sustainable future and the financial difficulties facing schools, Smart-POD is a unique and innovative research project which provides an alternative to traditional classroom planning. It proposes a rapid deployment building solution, transitory or permanent in its use, modular in design, flexible in set-up and self-sustaining in use, requiring nominal site works and providing for all of its energy demands from renewable energy sources. Its feasibility was tested via a design case study which investigated potential of its novel "thermal capacity on demand" energy performance approach. It combines a modular thermal storage solution capable of balancing heating demand and supply for a low rise, low mass superstructure with renewable technologies and the level of back-up power/services needed. The project team has formed a consortium of stakeholders and consulted on design methodology, performance specification and viability of other markets, the results of which are reported in this paper. The research has, in its final output, established a commercial model based on its design, procurement, financing, supply chain and the manufacturing strategy and is currently negotiating funding for the prototype.

Keywords: Thermal Capacity, Modular design, Sustainable, Rapid Deployment, Transportable

Nomenclature

Smart-POD – **S**ustainable **M**odular **A**utonomous **R**eusable **T**ransportable

1. Introduction

The Smart-POD was an externally funded research project with a research team that has identified a demand from Local Authorities and Educational Establishments for a flexible, modular and sustainable transitory classroom facility, in particular since the Building Schools for Future (BSF) capital investment cancellation in 2010 [1]. Despite the subsequent introduction of Priority School Building programme (PSBP) in 2011 [2] undertaken in two subsequent phases, PSBP1 in 2011 and PSBP2 in 2014, the identified requirement has retained its demand potential. In addition to the above identified need, the stakeholder’s feedback has pointed out to other viable and important commercial uses that should be explored, such as housing, tourism, community spaces, events and festivals, military, medical, business incubation and disaster relief. The key research objectives were set as follows:

1. Establish the technological, scientific, design, and regulatory information and methodologies relevant to the proposal. From the information gathered develop a brief outlining the initial User Requirement Specification.
2. Undertake research on a novel “thermal capacity on demand” approach and specify target energy performance benchmarks, including renewable technology and building performance required in order to meet this.
3. Produce a feasibility study for various methods of manufacturing and assembly.
4. Disseminate results via research publications and determine further funding opportunities.
5. Produce final pre-production prototype design drawings, details and specification, including illustrations.
6. Identify further collaborators and find the best option for route to market, procurement and finance model.

2. Thermal Store Solutions

The benefits of thermal storage have been enjoyed by humanity for thousands of years, since the times of cave-dwellers who found that the temperature inside remained virtually constant in both winter and summer. Today, different methods of storing thermal energy exist [3]:

- Sensible heat storage – utilising the specific heat capacities of materials by raising its temperature.
- Latent heat storage – utilising the energy requirements when materials change state, more commonly associated with phase changing materials (PCMs).
- Physical sorption heat storage – a physical and chemical process whereby one material becomes attached to another, releasing heat energy in the process.
- Chemical heat storage – heat is released by the exothermic reactions of chemicals.

It is estimated that heating accounts for between 45 to 47% of the total final energy consumption in the UK, with the space and water heating apportioned as 63% and 14% respectively, 80% of which is fossil fuel based [4]. More recently different thermal store mediums have been extensively explored [5], with storage concepts for solar and low energy buildings analysed providing empirical measures and cost comparison for different storage materials, in both open and closed systems. Alternative materials are also considered, for example sodium hydroxide and zeolite where the adsorption process releases heat, as water molecules attach themselves to the surface [6].

Depending on their capacity and time constant there are two types of thermal storage systems; diurnal and seasonal. Diurnal systems respond to the daily variations whilst the seasonal storage systems respond to the variations dependent on the time of the year. With seasonal systems, the thermal energy is collected whenever it is available and used whenever it is required, such as in different times of the year [7]. The thermal storage system can further be classified by the size on the small and large systems and by temperature on the low (<100ºC) and high temperature (> 100ºC) systems [4]. When specifying the sensible heat storage the choice of materials with high density and specific heat capacity need to be explored, such as water, rock, concrete, earth, granite, masonry, heat transfer oils and so on.

In this research low temperature diurnal sensible heat storage has been used [8], with a loosely packed rock bed as a medium. Faster response rate, lower temperature, lower energy losses and lower risk of boiling/freezing and leakage makes this option an economical alternative to seasonal storage [9]. Furthermore, the medium can often be sourced by recycling the existing waste on the site, giving it an added environmental benefit. In the compact site conditions, the size and thermal performance of diurnal and seasonal store envelope can often be restricted by the available storage space. Hence, to charge the stores to a required temperature level heat is often added by the heat pumps [9].

For seasonal stores a literature review by [10] determined that the effectiveness of seasonal storage systems is problematic to achieve with the current methods due to long term self-discharge. The key role is to balance the demand and supply requirements, but often on expense of longer running times compared to the concept of energy delivery on demand. They also have a higher percentage of energy storage loss compared to diurnal systems and their capacity and configuration will have a significant impact on the performance of generation and distribution systems [11][12]. Diurnal stores, on the other hand, can provide a significant "load shifting capability" and reduced energy losses, but the required storage volumes are large for the small to medium size building typologies and will only be fully resolved with improving the effectiveness and reducing the costs of latent or thermochemical heat storage systems [13][14]. There are promising developments and research reported for the smaller scale latent or thermochemical systems [15][16]. However, the choice between a single large store or smaller distributed thermal store systems can still be complex and certainly project dependent, as reported by [17], since the large systems have lower losses per volume of storage but require longer pipe runs and circulation pump when compared to distributed stores. Conversely, the latter sustain larger losses given their surface to volume ratio.

3. Research Methodology

The fundamental reason for choosing a case study approach was to establish a challenging user requirement specification and design brief for research study of a complex and innovative project, through a prism of collaborative research and partnership delivery model. This enabled a detailed assessment of the project proposal and its novel aspects based on the identified school site location, including the ability to corroborate findings with both industry and academic research partners, within the framework of proposed project aim and objectives. Simons [18] clarifies the validity of case study choice as a suitable research method, stating that: "A case study is an in-depth exploration from multiple perspectives of the complexity and uniqueness of a particular project, policy, institution, programme or system in real life context. It is research based, inclusive of different methods and is evidence-led. The primary purpose is to generate in depth understanding of a specific topic".

A case study holistic design method has been chosen for this research study. Yin [19] states that this approach is valuable when the methodology pertinent to the case study itself is of a general nature, which indeed is the case for modular buildings given the fact that their design has to provide an inherent deployment flexibility for a multitude of unforeseen conditions, without prior knowledge of the site location, its context and specific client requirements. Yin also highlights the importance of research being able to formulate real world scenarios, stating that otherwise the research may be overly abstract, with a lack of suitably clear outcomes, measures or data.

4. Design Strategy

4.1 Design

Smart-POD is designed as a sustainable, rapid deployment and potentially autonomous modular building solution, representing the outcome of the investigation undertaken into the combination of the technological processes involved. Principally, research into innovative thermal storage methods was conducted given the apparent lack of thermal mass that light weight modular building systems suffer from. Furthermore, research into off-site rapid construction methods, passive design techniques and principles, energy efficient building envelopes and renewable energy technologies was also undertaken, to balance energy requirements against the gains that can be made from its surrounding environment, including energy gains made whilst the POD is not in use. Its capabilities can be defined as follows [20]:

- **S**ustainable - both in terms of its cost and energy performance, with a novel concept of "thermal capacity on demand". Achieved BREEAM 'Outstanding' rating in 2012, as designed [21].
- **M**odular - allowing for it to be used as a standalone unit or as a cluster. Smart-POD is designed to allow schools to build flexibly, without significant changes to space or infrastructure.

- **A**utonomous, meaning it is designed as a self-sufficient unit, with an option of “plug and play” connections to existing school infrastructure and fixed services.
- **R**eusable, with a rapid redeployment to other sites.
- **T**ransportable, delivered to site by road and operational within 24 hours (post site and foundation preparation).

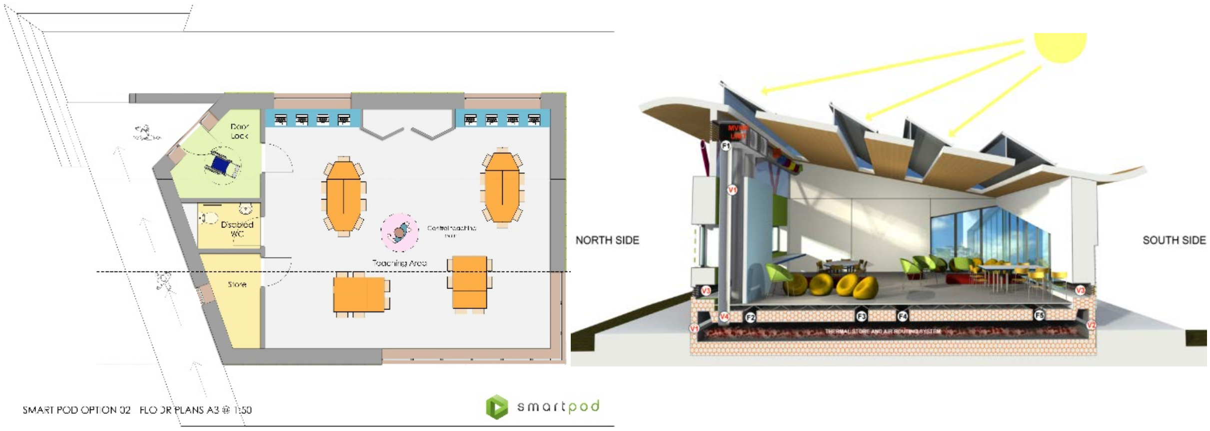

Fig. 1. (a) Plan View – Option 2; (b) Sectional View – with Integrated Thermal Store and Services (Source: Authors)

The proposed single classroom pod comprises of (see Fig. 1. a,b):

- Teaching area with a flexible furniture arrangement and central teaching point, including IT provision and easy access to outside, as per curriculum requirements in primary schools.
- Storage facilities and Approved Document M DDA compliant WC facilities
- An entrance lobby area for coat storage, with double “air lock” to minimise heat gains/losses.
- Large area of triple glazing facing south to south – east to maximise solar gains in the winter, with effective shading measures in the summer.

4.2 Specification Summary

Table 1 below gives the outline of technical and performance specification summary used in the Smart-POD project.

Table 1. Outline Technical and Performance Specification Summary

Design aspect	Performance specification summary
Building U-Values (W/m^2K)	All opaque surfaces = 0.1- 0.12 W/m^2K Windows 0.7-0.75 W/m^2K
Renewable energy	Solar electricity PV (Photovoltaic) panels
Passive strategies	Innovative concept of “thermal capacity” on demand. Passive stack - combination of cross ventilation, buoyancy and the venturi effect. Solar gains. Maximising natural light levels.
Ventilation – Dual mode	Natural ventilation and MVHR
Air tightness	$\leq$ 3-4 m^3/hm^2 @50 Pa (or $\leq$ 0.6 ACH @50Pa)
Heat distribution	Thermal Store MVHR distribution warm air system
Space Heating Demand and Load	< 25 $kWh/m^2/year$ and $\leq$ 15W/m^2
Overheating	<10% over 25 ^0C
MVHR efficiency	$\geq$ 90%
Electrical appliances	A+++ equivalent
Limiting Solar Gains In Summer	Solar shading / glazing specification
Cooling	MVHR inc. “summer bypass” function. Thermal Store.
Thermal Bridging	Accredited construction details. $\leq$0.01 W/mK
Lighting	100% energy efficient low energy lighting, dual occupancy light levels

Performance Monitoring and Energy Efficient Operation	Building management system (BMS); wireless data collection Log Book and Data Monitoring sheets, Performance Certification
"Plug and play" electric connection	Renewable energy generated during the summer period when not in use is returned to the main grid, generating income.
Non Potable Water	Rainwater harvesting for toilet flushing and urinals. Backup system- water tank. Groundwater borehole exploration.
Potable Water	Water fountains. Alternatively, a full rainwater to drinking water system, including filtering and UV treatment. Backup system- water tank.
Sewage treatment	Green Filter Septic Tanks. No smells, no drains, easy maintenance.
Air/Water Quality Control	Environmental Agency.
Structure	(Light weight framing system, METSEC, GRP or similar, as per structural engineer specification and calculations).
Secondary Heating and Thermal Store Top-Up	Air-to-air heat source pump.

4.3 Kinder-POD – Using Building as a Sustainability Learning Tool

The research has also been undertaken in relation to a Kinder-POD, aimed at creatively contextualising the role of the proposed building as a sustainable learning tool for children of up to 5 years old, in a way that is familiar to children of such a young age. The usual means of describing building performance via Energy Certificates with graphs and figures would obviously be incomprehensible for children of this age group. To overcome this, team proposed the use of *Greenview* [22], the web based system which is connected to real time performance monitoring of building, but instead of graphs and tables it allows children to perceive and understand building behaviour through interaction with a unique comic character (see Fig.2a). The concept is similar to that of *tamagotchi*, a handheld word famous electronic toy, which has to be cared for and looked after by the 'owner' as if it were a pet.

Fig. 2. (a) Greenview and Energy Certificates; (b) Building as a Sustainability Learning Tool (Source: Authors)

The aim was to support integration of sustainability within the national curriculum through a combination of education and fun, whilst enhancing children's individual learning needs, inspiring commitment to sustainability, helping to develop character and ability, encouraging teamwork and helping to support their social and moral development. The proposed design incorporates a *Greenview* based weather station, rainwater recycling point, energy meter and a solar powered timetable clock, amongst other visible sustainable building features (see Fig.2b).

4.4 Building Modes of Operation – "Thermal Capacity on Demand"

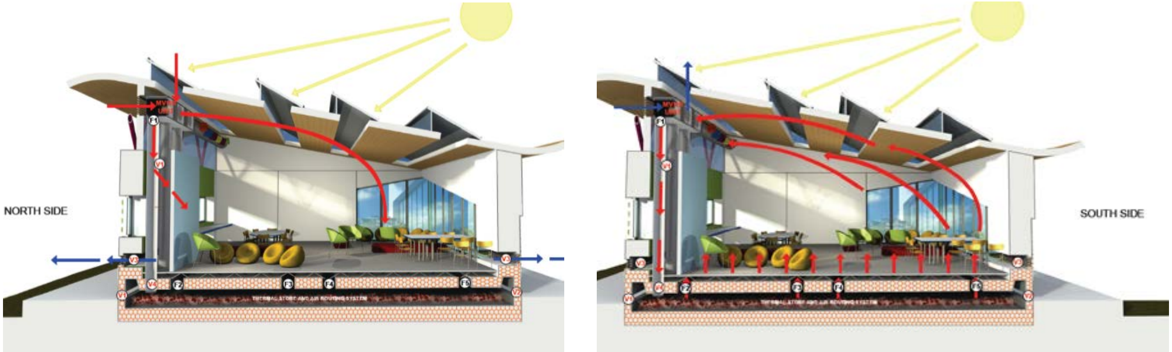

Fig. 4. Scenarios 1 and 2: (a) Heating without Thermal Storage Mass; (b) Heating with Storage Thermal Mass (Source: Authors)

Fig 4 visualises Scenario 1 *Heating Without use of Thermal Mass*. When the outside air is colder than the inside, fresh air is drawn in through the MVHR at the top of the building and heat exchanged with the outgoing warm stale air. The indoor air is further warmed by passive solar heat gains, latent heat gains from people, appliances etc. It fills the space from the top, displacing any stale cool air via the side vents (if needed), near the floor level. The sensor measures the temperature and if within the comfort band range, releases air directly into the classroom. If not, the fan drives air down through the heat store and the Fig 4 Scenario 2 *Heating from Thermal Mass* becomes current. In this scenario pre-warmed thermal store is now being used to heat the building, diffusing it evenly up through the floor grilles to avoid drafts, hot spots, and convection air currents.

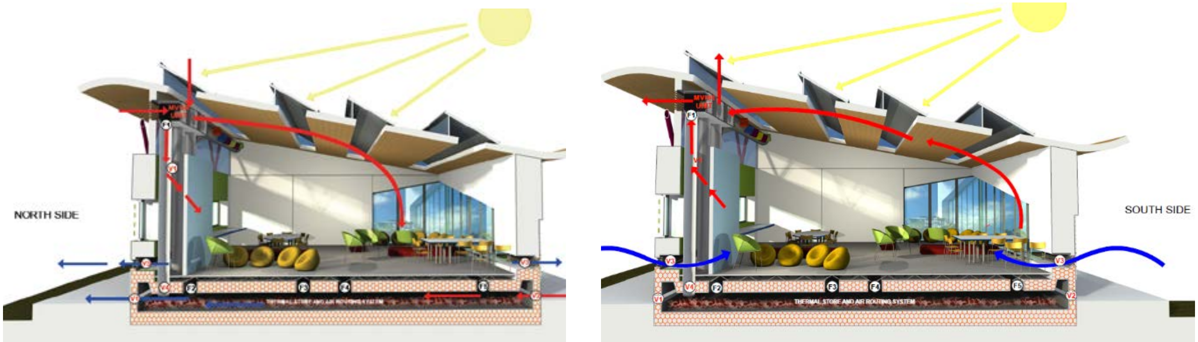

Fig. 5. Scenarios 3 and 4: (a) Ambient Heat Capture; (b) Day Cooling without use of Storage Thermal Mass (Source: Authors)

Fig 5 visualises Scenario 3 *Ambient Heat Capture* which demonstrates the consideration of occupancy patterns and passive design thinking. For example the pod is prepared for a Monday morning class on a sunny Sunday afternoon. Air is pre-warmed by the use of a contraflow air to air heat exchanger (MVHR) in which the fresh incoming air is heated by the stale outgoing air. The air is forced down, pushing any remaining cold stale air out through the side vents. The thermal store vents are open to allow warmer outside air in, passively displacing cold air inside and thus pre-warming the thermal store. Fig 5 Scenario 4 demonstrates the *Day Cooling without use of Thermal Mass*. When outside air is cooler than inside, but the building is overheating due to the latent and passive solar gains, the building may be cooled by allowing stale warm air to passively rise up and convect out of the building, replenished and “pushed up” by cool fresh air as it enters via the side vents. Penultimate scenario considers *Day Cooling of Space Using Thermal Mass*. The thermal store has been pre-chilled and is now being used to cool the building. The incoming warm fresh air is pre-cooled by outgoing air in a contra flow mechanical ventilation heat exchanger (MVHR). The sensor measures the temperature and if within the comfort band range, releases air directly into the classroom. If not, the fan drives air down through to the heat store and cools it further, diffusing it up evenly through the floor grilles. The fresh cool air will passively ‘pool’ at the bottom of the room, and warmed air will passively rise to the MVHR to be exhausted from the building. Final Scenario 6 considers *Night Cooling of Space and Thermal Mass*, by using lower summer night temperatures to pre-cool store in preparation for a hot day. The building is passively cooled by allowing stale warm air to rise up and convect out of the building, replenished and "pushed up" by cool fresh air, as it enters via the side vents. In addition, the cool air is passively drawn through the thermal store to cool it. As a system backup, the proposed secondary heating/cooling system is a reverse cycle air source heat pump, electricity powered.

5. Results

5.1 Thermal Capacity on Demand

The thermal modelling has been undertaken in accordance with CIBSE AM11 Building Energy and Environmental Modelling [28] and corroborated via calculations, summary of which is presented in Tables below.
For a typical primary school, CIBSE Energy Benchmarks TM46L 2008 [23] indicates a combined energy use of 190 kWh/m^2 of floor area per year (heating and electricity). More recently, tailored energy benchmarks for offices and schools were analysed from the sample of DEC data for 6,686 primary schools [24], giving an overall updated median value of 169 kWh/m^2 per year (125 kWh/m^2 - heating, 44 kWh/m^2 – electricity). Table 3 shows an estimated energy use for the Smart-POD to be significantly lower around 26kWh/m^2/year, based on 30 pupils and 2 teachers and floor area of 117m^2, with typical primary school occupancy profiles (including energy required for lighting, IT equipment, controls, fans and MVHR). An hourly heat gains of 75W per pupil and 140W per adult teacher were used in calculations, with 10 hours average daily occupancy assumed. The estimated average daily heat gains are in range of 17.4 to 26.6 kWh, giving projected temperature rises from 2.8 to 3.6ºC from the thermal store initial steady state of 18ºC, thus keeping the estimated ambient room temperatures in the 20ºC to 21.6ºC range (see Table 2).

Table 2. Heat Gain and Losses Calculations

Daily Heat Gains	Total daily gains (Wh)	Heat recovery efficiency (%)	Ventilation Loss (W/ºC)	Total daily losses (Wh)	Daily Gain/loss (Wh)	Estimated temperature rise/fall	Temperature reached
Jan	53883.44	90.00	31.52	26537.63	27345.81	3.14	21.14
Feb	55875.63	90.00	31.52	24831.64	31043.99	3.57	21.57
Mar	52463.13	90.00	31.52	21230.10	31233.02	3.59	21.59
Apr	45190.00	90.00	31.52	16301.69	28888.31	3.32	21.32
May	35105.63	90.00	31.52	10425.50	24680.13	2.84	20.84
Jun	35160.63	60.00	126.07	8746.00	26414.63	3.04	21.04
Jul	35097.50	45.00	173.34	5829.30	29268.20	3.36	21.36
Aug	35041.88	45.00	173.34	7949.05	27092.82	3.11	21.11
Sep	34916.88	45.00	173.34	17487.91	17428.96	2.00	20.00
Oct	38268.44	90.00	31.52	11752.38	26516.06	3.05	21.05
Nov	46769.06	90.00	31.52	19903.22	26865.84	3.09	21.09
Dec	52969.06	90.00	31.52	24831.64	28137.42	3.23	21.23

Thermal capacity of proposed thermal store (9m x 6m x 0.5m) filled with crushed rock is estimated to be 31320 kJ/K, using 0.58 fill factor, 0.12 W/m^{2}K U-value for the envelope and 8.28 W/K loss coefficient.

Table 3. Electricity Consumption

Source	Daily Consumption (kWh/day)	Yearly Consumption (kWh/yr)	Total Consumption (kWh/m^2)
Pupil equipment	4.2	903	
Staff equipment	2.1	451.5	
Lighting		636.48	
Controls	0.24	87.6	
MHVR / fans	3.12	936	
Total		3014.58	25.77

Its thermal capacity is such that it would require 8.70 kWh energy to raise its temperature by 1ºC. Should temperature in the store deviate from its steady state, the air-to-air heat pump would be used to lift the temperature to a required level. Table 4 below shows the estimated PV electricity generation of 5093 kWh/year, based on the adopted 40m^2 system collector area with 6.37kW peak power and 159.17 W/m^2 solar panel power. Given that the estimated electricity consumption is 3014.6 kWh/year (see Table 3), the Smart-POD has a significant "energy plus" net balance that could be exported to the grid, offsetting its carbon emissions and making it "carbon negative" in its performance. The above calculations are based on total of 215 school days per year, with an assumed average hourly equipment heat gains of 20W per pupil and 150 W per adult teacher, based on 7 hours of daily use.

Table 4. PV Electricity Generation and Carbon Emissions Estimate (Based on YingLi 260 W power output collectors)

System collector area	0	20	30	**40**	50	60	m^2
Panel power per area		159.17	W/m2	YingLi 260 W collectors (1.6335 m^2 single panel area)			
System peak power	0.00	3.18	4.78	**6.37**	7.96	9.55	kW
Generated elect / yr	0.00	2546.68	3820.02	**5093.36**	6366.70	7640.04	kWh
Consumed elect / yr	3014.58	3014.58	3014.58	**3014.58**	3014.58	3014.58	kWh
Net energy balance	-3014.58	-467.90	805.44	**2078.78**	3352.12	4625.46	kWh
Net carbon emissions	1643.55	255.10	-439.12	**-1133.35**	-1827.57	-2521.80	kgCO_2

5.3 Energy Consumption/Generation and CO_2 Emissions

Based on the model calculations and the CIBSE A2.34 met data (see Table 5), it is estimated that the Smart-POD energy use would be around 26 kWh/ m^2/year, compared to 169 kWh/ m^2/year for corrected CIBSE TM46L Benchmark [24], giving the 85% reduction compared to the typical school facility. In addition, the Smart-POD CO_2 emissions are 14.29 kg/ m^2/ year, compared to 92.1 kg/m^2/ year for CIBSE Benchmark (based on 117m^2 of the total floor area). The annual energy costs are calculated based on the average electricity costs of 14 pence per kWh, as published by Energy Saving Trust [27].

Table 5. Energy consumption and CO2 emissions – Comparison between CIBSE TM46L Benchmark and EMRE Smart Pod

		Annual Energy Consumption kWh/ m^2/ year	Anual CO_2 Emissions kg/ m^2/ year	Annual Energy Cost £/m^2/year	Annual Energy Consumption kWh/year	Annual Energy Cost £/year	CO_2 Emissions kg/year
Energy and CO_2 emissions	CIBSE TM46L Benchmark 2014	169	92.1	23.66	19773	2768	10776
	EMRE Smart Pod	25.8	14.29	3.60	3014	301	1643
	% reduction	84.7	84.7	84.7	84.7	84.7	84.7

Furthermore, the Smart-POD generates 5093 kWh/year, based on the adopted 40m^2 PV system collector area, giving the overall net performance of "energy plus" net balance of 2079 kWh/year, with net "negative carbon" emissions to an estimated amount of 1133 kgCO_2, (see Table 6).

Table 6. Net Performance – Comparison between CIBSE TM46L Benchmarks and EMRE Smart Pod

	Energy Consumption kWh/year	Value of energy £/year	CO_2 Emissions kg / year	Annual Consumption kWh/ m^2/ year	CO_2 displacement kg/ m^2/ year
CIBSE TM46L Benchmark 2014	19773	2768	10776	169	92.1
EMRE Smart Pod	-2079	-291	-1133	-17.76	-9.7

Compared to the corrected CIBSE TM46L benchmark, this provides annual amount of CO_2 emissions reductions of 11.91t for a single classroom, or 238t over a projected 20 years of building life for a transitory solution, and 715t over a projected 60 years of building life for a permanent solution. The latter is comparable to 71.5 large SUVs travelling 15,000 miles per year. Looking at the environmental versus cost impact comparison, based on the CIBSE TM46L classroom costs of £1,500/m^2 and Smart-POD of £1,650/m^2 with an average unit electricity costs as per [27], the payback period is estimated to 5.6 years (no interest rate, future value calculations or maintenance costs were taken into the account). The estimated payback period is based on a net difference in the construction cost of £17,550 for 117m^2 classroom facility, and a net difference in the energy consumption of £3,059 (£2,768 + £291) per year.

6. Discussion

The sustainable design performance analysis was undertaken in accordance with CIBSE AM11 Building Energy and Environmental Modelling [28] and within the constructs of BIM integrated approach at the conceptual stage, as explained in [25][26], and further corroborated via calculations, as summarised in Tables 2 and 3. Based on the model calculations and the CIBSE A2.34 met data it contains, it is estimated that the Smart-POD would generally be heated entirely by its users and their equipment all year round. Further sensitivity analysis on the extreme winter temperatures (10ºC below average) reveals that is still possible to maintain classroom temperatures of over 17ºC. In a similar manner, for extreme summer temperatures (10ºC above average) analysis shows that is still possible to maintain classroom temperatures of below 26ºC degrees, highlighting the effectiveness of thermal store and its integrated "thermal capacity on demand" approach. Relatively little additional effort of back up heat source would be required on those extreme temperature days to bring ambient temperate within the thermal comfort band range. Hence, the predicted performance of a proposed low temperature diurnal thermal storage solution indicates an effective climatic adaptability potential, enhanced by integrated passive design strategies and bespoke modes of building control. Together with renewable energy generation discussed in Section 5, it gives Smart-POD significant "energy plus" net balance that could be exported to the grid, offsetting its carbon emissions and making it "carbon negative". For the sites that have no facilities to allow export to the grid the backup system of battery storage is proposed.
The research is currently seeking further funding for a prototype to take it to the next stage of energy performance monitoring and in-situ measurements, as well as for finalising manufacturing, supply chain and costing strategy. Future research will consider different mediums such as PCM-based thermal storage systems, expected to become technically and economically viable in the near future [7].

7. Conclusions

The Smart-POD integrates existing technologies into a unique rapid deployment building solution, utilising the novel proposal for a thermal storage modular solution. This addresses the key environmental performance problem of all existing light weight modular systems, which is a lack of the thermal mass. The low energy design and integrated sustainable services research undertaken has resulted in technologically advanced concept of "thermal capacity on demand", that is supported via a system of heat recovery, thermal lagging, passive cooling and ventilation, passive solar gains, minimal heat losses, renewable energy generation and extremely high levels of insulations. The predicted performance of a proposed low temperature diurnal sensible heat storage system has been discussed, including six key modes of operation envisaged to control its energy supply on demand. Finally, the potential of Smart-Pod as a learning environment for children of up to 5 years old was explored, creatively contextualising the role of the proposed building as a sustainable learning tool in a way that is familiar to children of such a young age.

The research has identified several specific uses for the Smart-POD:

- Whilst refurbishing and/or retrofitting
- As rapid replacement for fire or flood damaged schools facilities

- To accommodate partial closure due to poorly maintained buildings
- As a quick, or phased, temporary or permanent response to predicted or confirmed increase in pupil numbers
- As a cost efficient, rapid build, alternative to traditional construction methods

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References

[1] Department for Education and Skills (2003), 'BSF - Consultation on a new approach to capital investment', available at: http://webarchive.nationalarchives.gov.uk/20130401151715/http://www.education.gov.uk/publications/eOrderingDownload/DfES%200134%20200MIG469.pdf
[2] Education Funding Agency (2016), 'Priority School Building Programme', avail.at https://www.gov.uk/government/collections/priority-school-building-programme-psbp
[3] Baoqi H., Hongyen Y., Dequan Y., Guoxi L. (2015) Utilization of natural zeolites for solar energy storage. Paper No. 9404 FAO Corporate document repository. Available at: http://www.fao.org/docrep/T4470E/t4470e0j.htm
[4] Eames P, Loveday D, Haines V, Romanos P. (20140, 'The Future Role of Thermal Energy Storage in the UK Energy System: An Assessment of the Technical Feasibility and Factors Influencing Adoption - Research Report', UK Energy Research Centre
[5] N'Tsoukpoe K.E., Liu H., Le Pierres N., Luo L. (2009), A review on long-term sorption solar energy storage. Renewable and Sustainable Energy Reviews 13, pp. 2385-2396
[6] Hongois S., Kuznik F., Stevens P., Roux J.J., (2011), Development and characterisation of a new MgSO4−zeolite composite for long-term thermal energy storage, Solar Energy Materials and Solar Cells, Volume 95, Issue 7, July 2011, pp. 1831-1837, ISSN 0927-0248
[7] Ampatzi E., Knight I., Wiltshire R., (2012), 'The potential contribution of solar thermal collection and storage systems to meeting the energy requirements of North European Housing', Solar Energy
[8] Steijger L.A., Buswell R., Smedley V., Firth S.K. and Rowley P., (2013). 'Establishing the zero carbon performance of compact urban dwellings', Journal of Building Performance Simulation, DOI:10.1080/19401493.2012.724086
[9] Steijger L, (2013),'Evaluating the feasibility of `zero carbon' compact dwellings in urban areas', PhD Dissertation, Loughborough University
[10] Pinel P.,Cruickshank C. A., Beausoleil-Morrison I., Wills A., (2011), 'A review of available methods for seasonal storage of solar thermal energy in residential applications', Renewable and Sustainable Energy Reviews 15 3341– 3359
[11] [Haeseldonckx D., Peeters L., Helsen L., W D'haeseleer W., 2007, The impact of thermal storage on the operational behaviour of residential CHP facilities and the overall CO2 emissions, Renewable and Sustainable Energy Reviews 11, pp. 1227–124311]
[12] Xu, J, Wang R Z & Li Y (2013). 'A review of available technologies for seasonal thermal energy storage', Solar Energy
[13] Pavlov G K & Olesen B W (2012). 'Thermal energy storage- A review of concepts and systems for heating and cooling applications in buildings: Part 1 – Seasonal storage in the ground'. HVAC&R Research, 18 (3), 515-528.
[14] Kenisarin MM (2010). 'High-temperature phase change materials for thermal energy storage', Renewable and Sustainable Energy Reviews, 14, 955-970.
[15] Finck C, Spijker H, Jong A, Henquet E, Oversloot H & Cuypers R (2013). 'Design of a modular 3kWh thermochemical heat storage for space heating application,' 2nd International conference on Sustainable Energy Storage, June 19-21 Dublin, Ireland.
[16] Agyenim F, Hewitt N, Smyth M & Eames P (2010). 'A review of materials, heat transfer and phase change problem formulation for latent heat thermal energy storage systems (LHTESS)', Renewable and Sustainable Energy Reviews, 14, 615-628.
[17] Grondzik, W.T., Kwok A.G., Stein B., Reynolds J.S. (2010), Mechanical and Electrical Equipment for Buildings, 11th edition
[18] H. Simons (2009), 'Case Study Research in Practice', pp. 21-25, Sage Publ. Ltd
[19] Yin, R.K (2009), 'Case Study Research: Design and Methods (Applied Social Research Methods)', pp. 50, Sage Publications, Inc.
[20] Ceranic, B. et al. (2013),' Smart-POD CRD Project Completion Report ', Sustainable Construction INet
[21] Code Green (2012),' Smart-POD BREEAM Assessment Report', BRE Approved Assessor
[22] Institute of Energy and Sustainable Development (2012), 'Green View', De Montfort University, [Online] Available at: http://greenview.dmu.ac.uk [Accessed: 14.03.17]
[23] Field, J. et. al (2008), 'Energy Benchmarks Energy benchmarks CIBSE TM46: 2008, Page Bros. (Norwich) Ltd., ISBN: 978-1-903287-95-8
[24] Boardass B, Cohen R, Burman E, Field J, (2014), 'Tailored Energy Benchmarks for Offices & Schools', CIBSE ASHRAE Technical Symposium, Dublin 2014, http://www.cibse.org/knowledge/cibse-technical-symposium-2014/tailored-energy-benchmarks-for-offices-schools
[25] B.Ceranic, S.Emmitt (2013) 'Architectural Technology – Research and Practice', Ch.3. Sustainable Design Analysis and BIM Integration, John Wiley & Sons Inc
[26] B. Ceranic, D. Latham and A. Dean (2015), 'Sustainable Design and Building Information Modelling: Case Study of Hieron's Wood, Derbyshire, UK', Energy Procedia, 83, pp. 434 – 443
[27] Energy Saving Trust (2017), Average Price of Electricity in UK–Our Calculations', http://www.energysavingtrust.org.uk/about-us/our-calculations [Accessed: 14.03.17]
[28] CIBSE (2015), AM11 Building Energy and Environmental Modelling, AM11/15, CIBSE