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The Early Design Stage of a Novel Solar Thermal Façade (STF) for Building Integration: Energy Performance Simulation and Socio-economic Analysis

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Abstract

This paper provides a feasibility study of a new solar thermal façade (STF) concept for building integration from both technical and economic aspects in Shanghai area of China. The whole set of technical evaluation and economic analysis was investigated through simulation of a reference DOE residential building model in IES-VE software and a dedicated dynamic business model consisting of several critical financial indexes. In order to figure out the cost effectiveness of the STF concept, research work consisted of: (1) exploring the overall feasibility, i.e. energy load, energy savings, operational cost and environmental benefits, and (2) investigating the financial outputs for investment decisions within three different purchase methods. This paper presents a multidisciplinary research method that is expected to be beneficial and supportive for the strategic decision at the early design stage and it also offers a different angle to assess the economic performance of the STF application.

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Keywords: Solar; Thermal façade; Energy Performance; Socio-economic analysis

1. Introduction

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Nowadays, the energy sector contributes to more than half of global greenhouse gas emissions. The building sector is one of the significant contributors to energy consumption and carbon emission while the fossil-fuel based systems for heating/cooling and hot water represents a major share. As a result, the built environment needs to be designed, built, operated and refurbished with much higher energy efficiency.

Solar thermal energy is one of the most promising renewable sources locally available for use in applications of building heating, cooling, hot water supply and even power production. At the beginning of 2015, Chinese authority released "*Renewable Energy Development Roadmap 2050"* as a long-and-medium-term plan for the development of solar technologies, showing a huge growing space for low-median temperature solar thermal application in supporting a stronger Chinese economy and a low carbon future [1]. Solar thermal is thus expected to offer a great potential for heat source diversity and to develop cities and towns in sustainable and affordable ways.

However, most solar thermal systems are predominantly applied in small-scale plants. The current demand contribution of overall domestic hot water and space heating worldwide was about 1.2% of the global solar thermal energy in building sector in 2013 while up to 84% was used for heating domestic hot water by small-scale systems in single family houses and only 10% was used for larger applications attached to multi-family houses, hotels, schools etc., [2]. Moreover, when solar thermal systems come to application in large-scale space heating plants in urban networks, the insufficient suitable-and-oriented roof of most buildings may dictate the solar thermal implementation. It is thus necessary to develop new solar thermal technologies with feasibility to be truly integrated with different building envelop components. Such requirement is expected to open up a large-and-new market segment of the solar thermal system for both new and existing buildings in need of energy efficient retrofitting and facade renovation.

Solar Thermal Facade (STF) is defined as the "multifunctional energy facade" that differs from conventional solar thermal modules as it offers a wide range of solutions in architectural design (i.e., colour, texture, and shape), exceptional applicability, and safety in construction, as well as additional energy production. It also has feasible functions in heating/cooling the building, providing hot water, comfort building environment and overall architectural appearance, which demonstrate a real sense of integration with building that can be potential solutions for the enhanced energy efficiency and reduced operational cost in contemporary built environment. In addition to the rising publics conscious on energy conservation in building, the prevalent implementation of multifunctional STF has been greatly driven by the aesthetic architecture desire, practical demand for improved indoor thermal performance, and the aspiration for on-site energy/thermal generation in a building. Although a remarkable R&D progress of the STF has been achieved, there is still large space open up for new research in this field.

This paper therefore proposes a novel compact solar thermal absorber with internally extruded pin-fin flow channel working as the metal claddings suiting for both new and existing buildings. The single-side-embossed absorber panel is made up by two metal sheets. One sheet is physically extruded by machinery metal roller which has concave pattern surface finish to formulate arrays of pin-fin corrugations, while the another sheet working as the absorbing surface remains smooth, and can be coated into optional colour or texture treatment according to different requests. The two metal sheets are welded together around the perimeter forming an absorber unity and built-in channels. In contrast to the traditional tubes-attached absorber, such built-in channel structure is designed to eliminate the utilization of redundant tubes and further enables a high flexibility in size or shape. In general, such a unique compact STF design engenders not only high heat transfer performance and economical overall cost, but also great feasibility in assembly of either parallel or series flow pattern for architectural design depending on various architectural and aesthetic requirements.

On the basis of this novel STF concept, a feasibility study of a new STF concept for building integration in a reference residential building was conducted from both technical and economic aspects in Shanghai area of China. This paper aims to present a multidisciplinary research to support the strategic decision at the early design stage and it also offers a different angle to assess the economic performance of the STF application.

2. Strategy of the techno-economic research

In terms of a new concept for building integration, the reliable theoretical analysis and simulation would be often a very effective and common way to investigate the adaptability and feasibility of the proposed concept in dedicated climate region, especially at the early stage for the building design or renovation. The simulation can compare the effectiveness of the proposed design in different scenarios affected by weather conditions, governmental policy, and energy tariffs etc., which presents the greatest opportunity to achieve the high energy performance buildings after construction or refurbishment. Since most of the energy system plans in building are usually decided in the early design stage, it is very useful to provide the pertinent energy performance information for the designers or decision-makers from multidisciplinary and comparative points of view. This research would be therefore useful in guiding the practical design of building design or renovation projects whilst using this proposed STF system.

Fig. 1 illustrates the research paths in providing strategic support in terms of the techno-economic approach for designers to make decisions about the application of the proposed STF concept during the early design stages of building design or renovation. Firstly, inputting the characteristic performance values from the validated STF simulation model into a DoE reference building model with other design parameters derived from ASHRAE standards; running reliable building simulation with the combi-simulation information which should have reasonable accuracy in predicting the overall building energy performance; and operating the integrated building simulation model all aim to estimate energy/carbon emission conservation potential and possible comfort challenge in building environment after using the STF concept in dedicated climate region. Then the adaptability and feasibility study under different scenarios would be carried out using the business model with basic financial data. Finally recommendations would be given for the strategic decisions for the building design or renovation with the proposed STF system at the early design stage.

Fig. 2 shows a schematic representation of the simulation process in IES-VE software that was used for the indoor thermal environment assessment, the dynamic time-step energy prediction, and the operating cost estimation of the STF concept implementation in a referenced residential building. The whole simulation involved with a suite of integrated analysis modules, as *Modelit*, *Suncast*, *Apachesim* and *ApachHVAC*. Firstly, both the building model and the proposed STF component were initially input in *Modelit.* And then, *Suncast* was utilized to pre-process all the exposed facade states for the purposes of annual time-series solar factor values, annual solar exposure hours and received solar energy. According to authors' previous investigation [4], the characteristic performance parameters of STF system derived from previously validated simulation model were input into *Apachesim* for the overall dynamic building environment modelling, while the controlling and auxiliary heating were realized in *ApachHVAC*. The whole simulation aimed to explore the thermal environment assessment, the dynamic time-step energy prediction and the operating cost estimation at the whole building level, thereby assessing how the integrated renewable technology interaction with building construction and its operational performance in a larger-scale application.

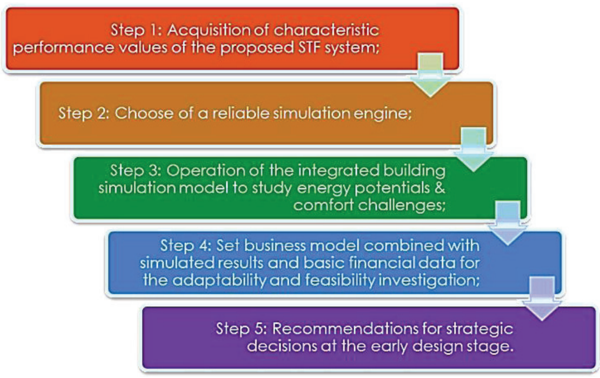


Fig 1 Multidisciplinary simulation strategy

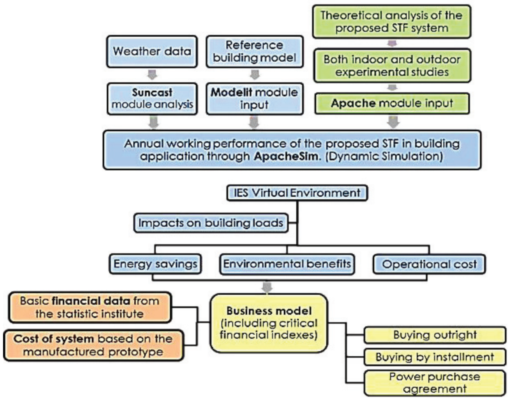
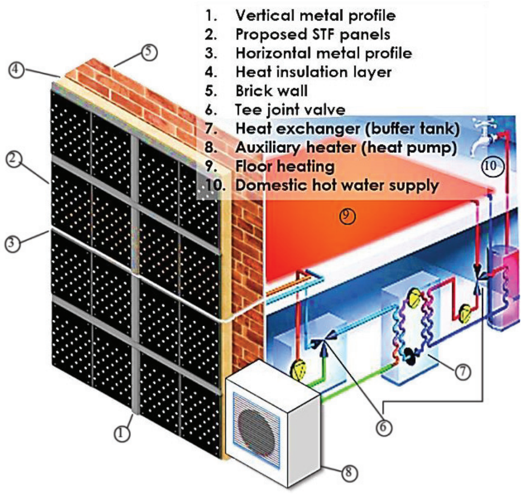


Fig 2 Schematic of simulation method by IES-VE software

3. Simulation model set up

3.1. Connections of STF component in the model

Fig. 3 presents a concept design of the STF system application in a multifamily household for hot water and space heating delivery. The STF modules are connected in the decentralized arrangement for each household unit, which allows the low-and-medium-temperature solar gain to be effectively delivered into the end user and so maximally reduces the sensitive transportation losses. And the schematic of system components connection for the proposed STF system in IES (VE) software and dimension of the reference residential building model are respectively shown in Fig. 4. The STF system was interacted physically with original building construction. It was operated with HVAC system synergistically throughout a year (only for hot water purpose in this simulation). The reference building plays a critical role in the energetic performance evaluation for the STF building integrated application through providing complete descriptions for whole building energy analysis under dynamic simulation software. All the dimensions and basic construction information of the reference building are derived from the DoE database [3]. The STF system was interacted physically with original building construction. It was operated with HVAC system synergistically throughout a year. The detailed data flow and components connection in the proposed STF system is presented in Fig. 5. It interprets how each component link to the others in both physical and information ways within the computer model. The proposed STF module was assumed as four stainless steel STF components (0.6 m×1m×5mm as modular size), closely clinging to original wall structure. In practice, there should be heat transfer interactions between the STF module and the building envelope. For instance, part of the heat loss from the STF module will be transferred into the building envelope in summer increasing the cooling load accordingly. On the other hand, the STF will also reduce the heat loss from the building envelope in winter period and decrease the heating load as a result. In the software, the basic interaction load represents as the external heat gain and temperature fluctuant feedbacks to the *Output File*.



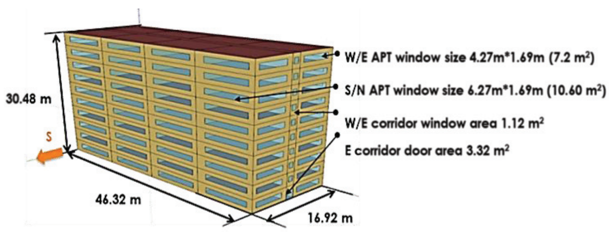


Fig 4 The reference residential building

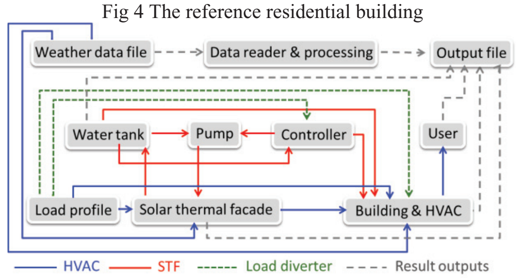


Fig 3 Concept of STF and dimension of the reference residential building

Fig 5 Schematic of system components connection

3.2. Characteristic performance of the STF system

The authors used a previously developed-and-validated steady-state simulation model [4] to characterize the STF's annual performance by inputting the monthly external weather data in Shanghai area. According to the simulation results, the plot of STF's thermal efficiency against the external weather and operational parameters $(T_{in} - T_a)/I$ can be determined by the linear fit method [5]. The regression result is presented in the following expression with a pleasant correlation coefficient, R^2 of 0.9958.

$$\eta_{th} = -1262.5(T_{in} - T_a)/I + 54.708 \quad (1)$$

where, η_{th} is the STF's thermal efficiency, %; T_{in} and T_a are respectively the temperature of inlet fluid and surrounding air, °C; I is the solar radiation, W/m^2.

The characteristic performance of the STF was considered as principal technical parameters into the integrated building energy simulation model within in the IES-VE software. It is believed that the solar thermal efficiency may vary with lots of factors in practice and they are very hard (sometimes impossible) to consider during the integrated simulation of building energy performance. In this case, most of simulation models currently apply the normalization method to simplify the simulation algorithm and focus on the specific impacting factors during the quantitative and strategic analyses. Based on this principle, this paper took the characteristic values of solar thermal efficiency derived from the equation (1) and considered them as the annual energy performance of the STF in broad terms during the simulation. Such approach weakens/downplays the impact of the variation of the system itself but emphasizes the overall impact of the STF system to the building energy performance and the corresponding economic strategies to determine their effectiveness in achieving energy savings during the early design stage of building renovation. It also needs to be mentioned that there were some assumptions in order to simplify the simulation at the early design stage. Based on the characteristic thermal performance and the preliminary estimation in the IES-VE software [6], the basic settings of a typical STF component are 1) the U-value of 0.46 W/m^{2}K; 2) the emissivity and solar absorptance of 0.9 and 0.97 respectively; 3) the optical solar thermal efficiency of 54.08%; 4) the first heat loss correction value of 4.04 W/m^{2}K; 5) the assumed internal heat exchanger effectiveness of 84% and 6) the assumed decentralized DHW delivery efficiency of 90%.

4. Dynamic building environmental simulation results

4.1. Annual temperature profile in the STF module

The annual mean temperature profile of the STF modules on the 5th floor was selected as a sample temperature distribution to study. The maximum temperature was set at 50℃ as the set-off temperature of the whole solar water heating system. As shown in Fig 6, the mean module temperature similarly fluctuated with the outdoor air temperature. Its vulnerability to environmental impact exactly fits the characteristic of the unglazed solar collector. The annual temperature range varied from 5.12 ℃ to 37.01℃ which were above the corresponding air temperatures during different months. It states that lower risk in freezing and stagnation problems and can contribute energy to the DHW load yet it requires further heat upgrade to achieve a required heating supply temperature.

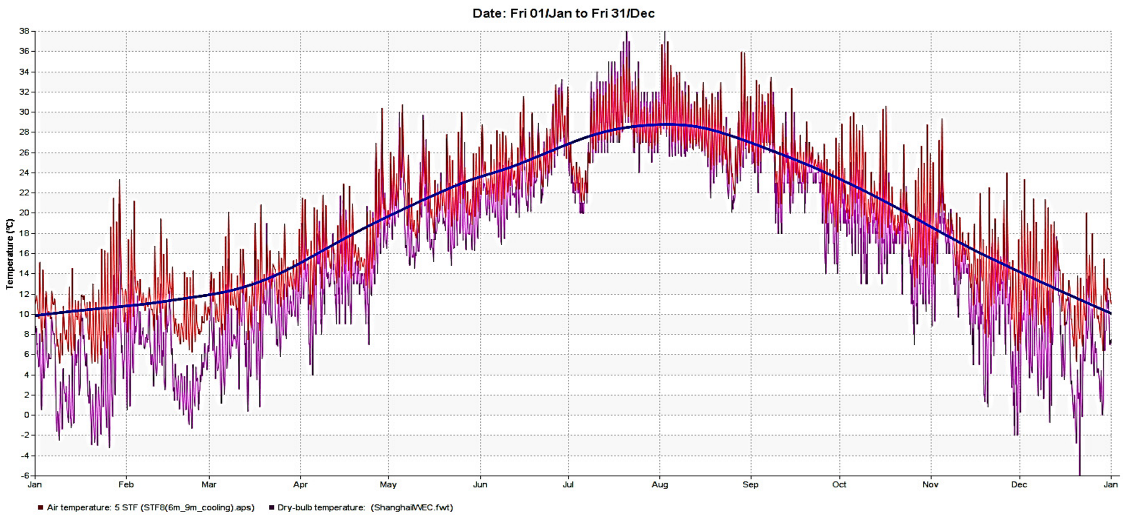


Fig 6 Annual mean temperature profile of the STF module on the 5th floor from IES (VE)

4.2. Water temperature profile in the system tank

Before the heating system starts to operate, the water temperature in the tank is heated up directly from the solar radiation source. As a result, it provides an intuitive way to assess the quality of useful solar resource achieved by the STF. From Fig. 7, it is known that the temperature of water in the tank varied a lot in the early months and most of them were below the 50°C temperature requirement. This was sigficantly affected by the small amount of vertical solar heat gain during the early months. Especially in June, the available solar heat again on the vertical surface became the least, leading to the lowest water temperature profile in the tank in this month. Afterthen, the water temperature remained at high level in consistency with the variation of the solar heat gain. It is obvious that the water temperature varied dependently with the solar gain. The frequency in variations of the water temperature above certain temperature levels can be summarised as:

- the dedicated temperature was above 50°C in about 2.1% period of a year;
- the dedicated temperature was between 45-50°C in nearly 32.2% period of a year;
- the dedicated temperature was between 40-45°C in around 23.2% period of a year;
- the dedicated temperature was between 35-40°C in about 21.3% period of a year;
- the dedicated temperature was between 30-35°C in about 15% period of a year;
- the dedicated temperature was between 25-30°C in around 6.1% period of a year;
- the dedicated temperature was below 25°C in only 0.1% period of a year;

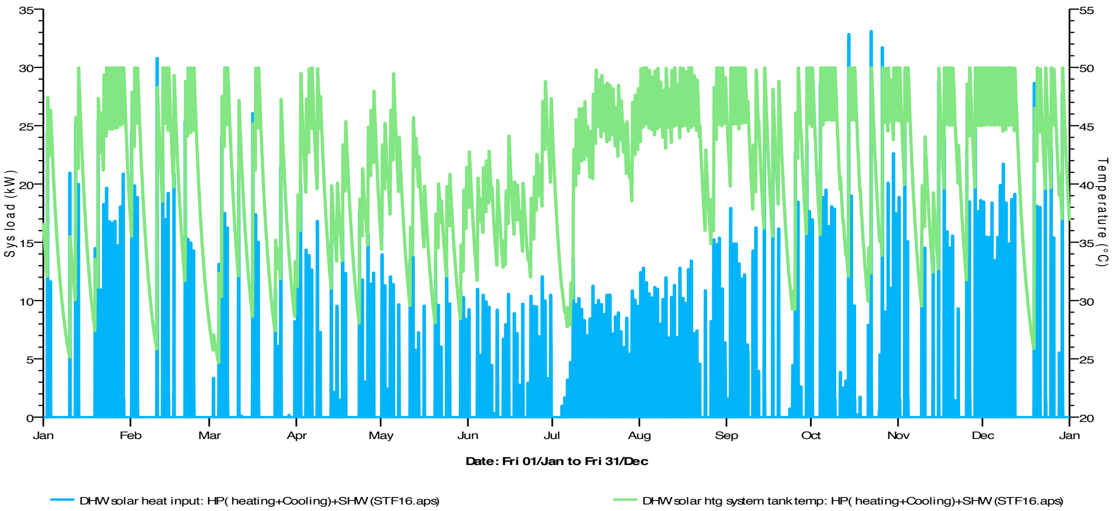


Fig 7 Annual variations in DHW solar water tank temperature against solar heating gain from IES(VE)

4.3. Impacts of the STF system on energy load

Table 1 displays the breakdowns of heating and cooling loads of the reference building, as well as the solar heat input. The simulation results indicated the total amount of contribution coming from the STF was 9367.6 kWh, and the contribution ratio had a uniform distribution annually. Regardless of the delivery efficiency, the specific solar thermal energy yield from STF per year was around 48.79kWh/m^2. Apart from the direct contribution to heating load, more indirect impacts have been found. As a whole, the application of STF resulted in a general decrease in space conditiong load. But the impact on the heating load was relatively greater than the cooling load. In summary, the total heating load also decreased from 217.729 MWh to 199.303 MWh, with an average decrease rate of 2.3%, while the total cooling load decreased from 207.502 MWh to 206.208MWh with an average decrease rate of 0.55%.

The addition of the STF into the residential building affects the overall building energy performance due to changes in the emissivity and solar absorptance of the building envelop. By means of the dynamic building environmental simulation, Table 2 listed the external conduction gains in the typical floor, 5th floor, which specially demonstrated the different heat transfer amount through the envelope coupled with STF and the conventional ones. In general, the total external conduction gain through the envelope coupled with STF was less than in the conventional ones, showing that the application of STF was useful to reduce heating/cooling load.

As a result, the overall contribution of the STF application in such a case included both the direct solar heat gain (energy generation) and the decrease of indirect heating/cooling load (demand reduction).

Table 1 Monthly breakdown of heating/cooling loads

Month	Sys cooling cond'g load	Sys boilers space cond'g load	Sys cooling cond'g load	Sys boilers space cond'g load	Solar heat input	Space cond'g load decrease rate
	Baseline (MWh)		STF coupled envelope (MWh)			
Jan	0	66.018	0	64.770	0.733	1.89%
Feb	0	49.673	0	48.648	0.650	2.06%
Mar	0	28.371	0	27.612	0.655	2.`67%
Apr	0	3.460	0	3.375	0.754	2.45%
May	0	0	0	0	0.689	0.00%
Jun	29.433	0	29.350	0	0.723	0.28%
Jul	76.509	0	75.998	0	0.848	0.67%
Aug	75.514	0	74.947	0	0.991	0.75%
Sep	26.045	0	25.914	0	0.836	0.50%
Oct	0	0.525	0	0.514	0.861	2.10%
Nov	0	12.704	0	12.347	0.800	2.81%
Dec	0	42.130	0	41.223	0.828	2.15%
Summed total	207.502	202.880	206.208	198.490	9.368	2.16%

Table 2 External conduction gain comparison of typical floor apartments

Month	Baseline (MWh)	STF coupled envelopes(MWh)
Jan	-3.785	-3.631
Feb	-3.111	-2.984
Mar	-2.566	-2.462
Apr	-1.624	-1.578
May	-1.745	-1.694
Jun	-0.740	-0.722
Jul	0.831	0.788
Aug	0.861	0.810
Sep	-0.854	-0.834
Oct	-1.989	-1.940
Nov	-2.292	-2.221
Dec	-3.069	-2.955
Summed total	-20.083	-19.422

4.4. Energy saving, environmental revenue, and operation cost

On the basis of the caloric value, carbon emission factor and individual energy tariffs in Shanghai, the simualtion was performed to calculate the energy consumption, carbon emission and operational cost of the whole building presented in Table 3. In terms of annual energy consumption, the dedicated building showed substantial savings in total energy consumption with 652,181.7 kWh. Although the additional system auxiliary and pump energy consumption slightly added, the overall energy still has a net energy conservation amount of 85,270.4 kWh.

In terms of annual CO_2 emission reduction, the STF device contributed a total carbon emission reduction of 69,239.6 $kgCO_2$ on the condition that 1 kWh of grid electricity emits 0.812 kg of CO_2 in the east region of China.

When this energy saving amount is transferred into the standard coal amount for Chinese energy efficiency subsidy application, the saved standard coal weight is around 9.5 ton. While in terms of annual operational cost, the savings caused by STF application through modelling was about ¥93,797 per year. Meanwhile, the total investment was shown in Table 4 that comprises the cost of each component, sale profit (30% of the sub-total cost), Value Added Tax (VAT) (17% of profit) and installation cost (30% of the sub-total system cost). The total initial investment of the STF upgrade (total 80 sets) for the whole building was estimated of ¥423,798. From an engineering perspective, it is usual to access the annual operational savings to appraise the cost effectiveness of an emerging technology. The result of annual operating savings shows that the Static Payback Period (SPP) of the STF investment is around 4.5 years. Through the quick and approximate assessment, the STF upgrade could be initially regarded as an acceptable investment option. However, the payback period is a relative longer period, overlooking basic finanical related elements, such as cost of capital, cash in-/outflow, depreciation cost and installment etc,. Meanwhile various payments/revenues and energy conservation measures envoled are unneglectable. Therefore, it is worthy to study the economic outputs with a detailed busniess model to evaluating the STF implemention using a dynamic Economic and Financial Analysis (EFA) addresed in follwing section.

Table 3 Annual energy consumption, carbon emission and operational cost

Date	Total energy (MWh)		Total system CE (kgCO_2)		Total energy bills (¥)	
	Baseline	STF upgrade	Baseline	STF upgrade	Baseline	STF upgrade
Jan	80.523	66.585	65384.838	54067.182	89380.752	73909.572
Feb	67.401	56.250	54729.774	45674.675	74815.332	62437.056
Mar	60.347	51.967	49001.845	42197.204	66985.281	57683.370
Apr	45.521	41.186	36963.133	33443.032	50528.421	45716.460
May	45.098	41.168	36619.657	33428.497	50058.891	45696.591
Jun	57.483	51.886	46676.196	42131.594	63806.130	57593.682
Jul	81.031	75.092	65796.766	60974.623	89943.855	83352.009
Aug	80.564	74.570	65417.643	60551.002	89425.596	82772.922
Sep	55.893	50.127	45384.710	40703.286	62040.675	55641.192
Oct	45.380	41.329	36848.398	33559.392	50371.578	45875.523
Nov	50.482	44.668	40991.140	36270.335	56034.687	49581.369
Dec	67.730	57.353	54996.922	46570.717	75180.522	63661.941
Summed total	737.452	652.182	598811.105	529571.540	818571.831	723921.687

Table 4 Capital cost calculation sheet of one set STF system application

System components	Unit cost (¥)	Quantity	Cost (¥)
Absorber module(0.6m*1m)	500.0	2.4	1200.0
Electrical water pump	200.0	1	200.0
PPR pipe fittings	200.0	1	200.0
Control system	1500.0	1	1500.0
Insulation backboard (m^2)	5.2	2.4	12.5
		Subtotal cost	3112.5
		Installation cost (30% of sub-total cost)	933.7
		Pre-tax profit (30% of sub-total cost)	933.7
		VAT (standard 17% of profit)	317.5
		Capital cost of each compact unglazed STF system	5297.5

Note: the standard Value Added Tax in China is 17%; the CPI in Shanghai is 61.26 (09.2015)

5. Economic feasibility analysis

A dedicated business model is specially set up to appraise the proposed STF system in term of monetary form. Compared to the static method, the adapted dynamic approach considers the value of monetary flows depending on the time at which the transaction takes place.

5.1. Key parameters

In reality, there are a variety of fundamental criteria for the uncertainty assessment in each investment project [7]. The most popular parameters are: 1) the Net Present Value (NPV) that takes uncertainty into consideration; 2) the Internal Rate of Return (IRR) makes the profitability of investments measuable to compare its anti-risk capability, and 3) the Dynamic Payback Period (DPP) that presents the direct return time of investment. They are general approaches in determining acceptance or rejection in different decision for a project that treats the cash flows as known with certainty using spreadsheets in Excel [8].

To compare different investment schemes on a common basis, each year's net cash flow (CF) needs to be multiplied by a discount factor so that all inflows and outflows linked to a given investment can be compared on a 'present' day level. When comparing several investments, the project with the highest positive NPV is usually the most attractive [7] .

$$NPV = CF_0 + \sum_{i=1}^{n} \frac{CF_i}{(1+r)^i} \tag{2}$$

Another economic appraisal factor, IRR is calculated from the NPV equation on condition that there is such an interest rate for which the NPV is equal to zero [9]. The IRR rule states that if the IRR on an investment is greater than a pre-defined cut-off discount (typically, sum of the cost of capital and the inflation rate), then a given investment project will be viewed favorably. The IRR balance equation is given as [7] :

$$CF_0 + \sum_{i=1}^{n} \frac{CF_i}{(1+IRR)^i} = 0 \tag{3}$$

The DPP is calculated by the means of simply written in the following Equation (4). It is obvious that the smaller value, the quicker the payback time.

$$DPP = n_k + \frac{\sum_{i=0}^{k} CF_i}{CF_{k+1}} \tag{4}$$

In above equations, the related parameters are addressed as followings: *n* (an integer) is the project duration in assumed time years; r (a positive real number) is the required rate of return of the investment or cost of capital (for the way the r is determined and various assumptions that are made); C_OF_i (a non-negative number) is the cash outflow at the end of the ith year (i = 0; 1……*n*) and C_IF_i (a non-negative number) is the cash inflow at the end of the ith year (i = 1……n). Both yearly cash flows will be often summarised as a single cashflow CF_i, occurring at the end of the ith year (i = 0; 1……n), where $CF_0 = - C_OF_0$; $CF_i = C_IF_i - C_OF_i$ (i = 1……n); n_k is the last period with a negative cumulative cash flow; CF_{k+1} is the total cash flow during the period after year k.

5.2. Background financial parameters

DPP, NPV and IRR were selected to evaluate the investment feasibility of the proposed STF system applied in a reference high-rise building. As mentioned in Equations (2)-(4), the calculation of the key parameters contains background parameters, such as the initial investment of a system, inflation rate and local annual capital cost, etc. The initial investment of the compact unglazed STF system was provided from the same manufacturer of the prototype. And Table 5 displayed all the required basic statistics data for the financial calculation. Via referencing the statistical data from the Chinese domestic sector, the mean annual rate of Consumer Price Index (CPI) (=2.92% from 2005 to 2014) and the average one-year interest rate of saving account (=2.90% from 2005 to 2014) were deemed suitable for representing the inflation rate and the interest rate of private equity [10]. Besides, operational and maintenance costs, and rent from tenants are assumed.

Table 5 Basic parameter inputs in the business model

	Items	Value	Note
STF data	Investment costs	423,798	¥
	Total lifetime	25	yrs
	Depreciation Straight line rate	0.04	
Building characteristics	Annual maintenance deduction	0.02	Caused by STF
	Rent current state[1]	72,000	¥/(apt-yr)
	Fixed plug electricity fee[2]	6,129	¥/(apt-yr)
	O&M charge (Tenant)	100	¥/(m^2-yr)
	HVAC+DHW charge (Tenant)	47	¥/m^2
	Overhead multiple	20%	
Energy cost	Electricity tariff[4]	1.10	￥/kWh
	Heat capacity per unit of electricity[4]	860	kcal/kWh
	CO_2 emission per unit of electricity[4]	0.812	kg CO_2/kWh
Economic data	Amortization period	15	yrs
	Inflation (10-yrs mean CPI)[1]	0.029	yr
	Energy growth rate (incl. inflation)	0.079	yr
	Discount rate[5]	0.1	yr
	Interest rate of private equity[1]	0.029	yr
	Commercial interest rate[1]	0.072	yr
	Business tax deduction[6]	0.030	yr
ESCO fiscal benefits	Corporate income tax	0	1-3yrs
		0.125	4-6yrs
		0.250	after 7yrs
	Energy efficiency subsidy	600	¥/ton standard coal

Note: 1) Data from Numbeo worldwide living database, http://www.numbeo.com/cost-of-living/city_result.jsp?country=China&city=Shanghai;
2) It covers appliance & equipment loads and lighting load. Calculation assumptions are referenced from Hendron R. 2008. Building America Research Benchmark Definition. National Renewable Energy Laboratory, Golden, Colorado);
3) DHW consumption is referenced from Kalogirou S. 2009. Solar energy engineering processes and systems;
4) Data from local utility suppliers (09 Sep 2015); the solar water tariff was based on 50% of electrical water heating cost (90% in efficiency);
5) 10% for building service appliance;
6) Fiscal benefits are referenced from http://news.ces.cn/fuwu/fuwuzhengce/2015/09/25/75688_1.shtml.

5.3. Setting up business model of the STF

The buisness model has taken four states into consideration, as 1) 0. Current state; 2) A Private equity; 3) B. Loan from bank to owner; 4) C. Operate leasing. The four states invovled with three main investment schemes: (1) *Buying Outright* (BO); (2*) Buying by Installment* (BI); and (3) *Power Purchase Agreement* (PPA). These different schemes are the prevalent finance methods for renewable technology investment on the market, and can basically cater for different circumstances with individual key benefits. BO and BI are common purchase for the building owner. Unfortunately, the renewable subsidy program is only accessible to the public party or *Energy Service Company* (ESCO) at the moment in China. Therefore, PPA is other prospective purchase scheme emerging in China. There are a number of reasons to involve an ESCO in a renewable technology investment. Firstly, it prevents a financial risk in making the upfront investment. Secondly, the whole investment can be paid back in the user phase by energy savings. Thirdly, an ESCO is able to enjoy plentiful fiscal or other benefits currently in China when carrying out an energy conservation investment. What is more, an ESCO is a pofessional party to provide outsource services of new technology upgrade, building energy management and O&M.

In this case, it is assumed that in the 0. state, the tenant pays a fixed fee (including rent, fixed energy service fee covering fixed amount of both electricity and HVAC consumption, and routine O&M service) to the building owner, and the latter takes care of the public service, supplements of fixed amount electricity, HVAC, DHW and routine O&M service. In the A and B state, it is assumed that the tenant still pays the same rent for the upgraded mordern building outlooking and improved indoor comfort, and keeping the same amount payment of electricity, HVAC, and routine O&M service to the building owner. And the building owner benifits from savings on energy consumption and additional 2% of O&M expense deduction cased by STF upgrade compared to the DHW operation in 0 state. The only difference between BO and BI lies in the finance method. BO invested the project through A. private equity meanwhile BI inested through B. commercial loan from bank.

The scenario is a little different in the C state. In the PPA scheme, the tenant still pays the same amount of rent and the fixed amount of electricity, HVAC, and O&M expense to the building owner, while the building owner authorizes an ESCO to run operate leasing of the STF system. As mentioned previously, given that STF system invested by ESCO can reduced the total energy for the building owener, the energy savings should be shared between the ESCO and the building owner with the ratio of 9:1. But in the end of the amortization period, the building owner will have the ownership of entire STF system (¥10,467's at that time). Moreover, because an ESCO is a kind of orgnization that provides technical assistances and services to promote energy conservation activities to the society, Chinese government has released a series of fisical benifits to foster its rapid growth. Currently, an ESCO can benifit from a business tax deduction (5%), a corporate income tax (0% during1^{st}-3^{nd} yr, 12.5% during 4^{th}-6^{th} yrs and 25% after the 7^{th} yr), application of Energy Efficiency Funding (with green credit interest rate of 6.2%) and one-off energy efficiency subsidy (¥600/ton of stand coal equivalent in Shanghai district in 2015).

5.4. Results from the business model

On the basis of basic fundamental parameters from Table 4, key parameters from three STF investment schemes can be summarized in Table 6. The STF investments in the reference residential building in Shanghai seemed to be all profitable with positive NPVs within 15 years and greater IRRs than the pre-defined cut-off discount. In terms of DPP, it was found that all the DPPs were within 6 years, which is cost effective for a kind of building service application and matches the initial design objectives of lower cost and fine operating performance. When looking into each investment scheme, three schemes had quite different outputs. Firstly, the popular BO scheme actually has a gentle outcome for an investment decision. Because of the feature in buying outright, the inflexible payment method has the lowest acquisition outlay and avoidance of annuities in the coming years. However, the NPV over 15 years was the least. In another word, it can be regarded as the saftest investment method with the lowest financial risk and longest DPP. Similar to BO, BI is another self investment option yet with a more flexible payment method using installment. With the assumed 7.2% commercial interest rate, all the financial outputs presented with an attractive financial outcome. Although the overall investment cost is much higher than BO, BI yet had the optium performance with highest IRR and the shortest DPP. Looking into the financial calculation process, it could be found that the positive contributions coming from: 1) the amortisation payment made the time value of money to be additional profit for building owner; 2) the annual installment amount is considered as "tax deductible" item in the corporate income tax during the financial calculation. But this purchase scheme still has to face the potential risk in fluctuation of commercial interest rate. As compared to both BO and BI, EEF is an evolutionary option by the third party ESCO and available for all businesses, with an aim of helping customers for energy conservation whilst budgeting through affordable payments. Ideally, the savings on energy consumption and fiscal benefits render the STF upgrade beneficial to both the building owner and the ESCO itself. Benifit from both the energy saving and the lower green credit interest rate of 6%, the financial outputs seemed to be most acceptable in terms of NPV, IRR, and DPP. When combining the NPV from the involved stakeholders, it had the maximum NPV. In the perspective of the ESCO, it has got a much higher IRR of 56.6% to overcome common finianical risks, and could reclaim all the investment with a rapid DPP period with 3 years and 6 months. In the perspective of the building owner, although the profit had been shared with a third party, it would actually take advantages of 1) flexibility in budgeting to conserve existing working capital; 2) energy savings from solar thermal application; 3) upgrades in both the property value and the built environment; 4) the pofessional O&M service of the STF system for 15 years without any upfront cost; and 5) the free ownership of the STF system for the remaining 10 years.

Overall, this comprehensive business model helps to elaborate a suitable investing way of the proposed system deployment for the building owner. In view of the shortest DPP, the investment scheme of BI is recommended with both the highest NPV and the highest IRR. In view of the upfront investment, the investment scheme of PPA is recommedned with no capital investment at all and acceptable NPV and DPP.

Table 6 Financial outputs from different STF investment schemes

Options		Investment cost	NPV (15 yrs)	IRR	DPP
BO scheme (A)		¥423,798	¥594,674	27.4%	5yrs 2mths
BI scheme (B)		¥706,803	¥700,435	126.9%	1yr 11mths
PPA	Owner (C)	¥663,111	¥445,638	--	--
	ESCO		¥342,694	56.6%	3 yrs 6mths

4. Conclusion

The feasibility study indicated that the overall contribution of the STF application in a reference building included both the direct solar heat gain (energy generation) and the decrease of indirect heating/cooling load (demand reduction) as well as the corresponding reduction in carbon emission and operation cost in the humid subtropical climate region of Shanghai. A dynamic business model was additionally developed to appraise the cost effectiveness of this emerging technology in a monetary term. The financial outputs from the dedicated business model stated that: (1) the proposed system is a profitable investment project for the building implementation with positive overall revenue and acceptable payback period; (2) The investment scheme of the Buying Outright (BO) has the safest investment performance with the longest payback period of 6 years and 10 months; (3) The investment scheme of the Buying Installment (BI) has the moderate investment performance with a higher investment returns and a much quicker payback period of 2 years and 10 months; (4) The investment scheme of the Power Purchase Agreement (PPA), involving with an Energy Service Company (ESCO) has the most satisfying financial outputs with maximum returns as well as shortest reclaim period of 2 years and 6 months.

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