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Analyzing factors in emerging computer technologies favoring energy conservation of building sector

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ABSTRACT

Many Strategies and technologies have been tried and tested to attain energy efficiency in buildings. Internet based new age computer technologies are one among them. These new age digital technologies face resistance and lack of acceptance from the industry in initial stages. The prolonged acceptance in the society could be avoided and the rate of acceptance would be much faster if the characteristics of this technologies would have been known. The adaption of these technologies into energy conservation sector would be far easier if the factors favouring energy conservation by these new age technologies are identified. This research work is conducted to identify the critical factors that influence conservation of energy in buildings by adaption to new age digital technologies. The critical factors are ranked and prioritized based upon their weightage by using Best Worst Method (BWM). Among the main technologies, results show that blockchain technology is at the forefront followed by Internet of Things and Machine learning. Among the fifteen subfactors Real time execution, Security and Transparency are the top three factors favouring the digital technologies. The limitations and further scope of this research is also discussed in this paper.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Advances in Materials Research – 2019.

1. Introduction

Energy is a fundamental necessity for building operations in residential and commercial buildings. The routine domestic operations in residential houses and commercial activities in commercial buildings need energy for their day to day activities [1]. New technologies and new strategies to achieve energy efficiency are being introduced with the aim of achieving conservation of energy. 21st century Computer technologies are one among the novel technologies introduced in energy efficiency field [2,3]. Fig. 1 provides the various activities in building energy sector using blockchain technology.

For complex problems arising in energy sector due to diversified use of electricity for various application, It deserves a modern solution compatible with 21st century technologies. There could no better solution that could be inline with computer based new age technologies that are discussed in this paper.

1.1. The research problem and motivation

Whenever a new technology is introduced into the Mainstream energy efficiency market, it often finds resistance and lack of acceptance within the society. There may be various reasons for lack of acceptance for example: rigorous regulatory framework [9], lack of knowledge by users and non-intuitive characteristics. India initially banned Blockchain based Cryptocurrency in 2018 and finally lifted the ban after a span of two years[4], this is a clear indication that it took two years to realise the potential benefits of blockchain. If the characteristics and factors of blockchain technologies have been known in early stages of technology application, there could have been no ban and the acceptance rate of blockchain would have been widespread, resulting in huge economic advantage. This research is motivated by the above example of blockchain based cryptocurrency and aims to expose the driving characteristics of new age computer technologies in Building energy efficiency sector.

This research work has listed factors that leverage the acceptance of specific computer technology in energy sector.

This seminal work tries to answer the following research

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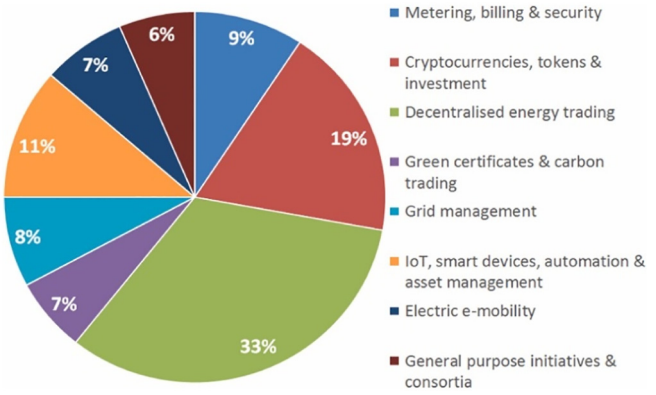

Fig. 1. Classification of Blockchain activities energy sector. *(Source:* Fig. 1 *Andoni et. al., 2020*).

1. What are the novel computer technologies in that can optimize the energy consumption in buildings?
2. What are the key driving factors for the novel computer technologies that make it popular candidate for acceptance in the society for practical application?

Energy market, specifically the electricity market is in transition phase to accommodate the latest technological advancements [9]. A recent work by Andoni et al. [9] has enumerated the characteristics of novel technology in energy sector. While describing the opportunities, and challenges it also points outs risks in energy sector using blockchains. Gill et al. [20] in his works has presented an nexus of blockchain, Internet of things and Machine learning. It provides detailed picture of applications of triumvirate consisting of IOT + AI + Blockchain, the details of Internet of Energy is also described.

Practical experiments conducted by Rafsanjani et al. in commercial buildings reveals that IOE can be used successfully to achieve energy savings by altering the occupant behaviour[13]. Internet of things (IOT) is contemporary with almost every computer technology in present days, IOT can be used in domestic residential homes to save energy. It can also be used for large commercial complexes and also finds huge applications in SMART cities [14]. IOT can be integrated with many building systems like HVAC, lighting and Automation to achieve resource management. It can be synchronised with blockchain and Machine learning to achieve intended results [15]. Further Data driven machine learning models are being widely used in building energy efficiency sector [17]. Because Machine learning models have the potential to explore modelling in building energy systems and can also develop methodologies for energy efficiency [19]. Goa et al. [18] in his works has presented sixteen machine learning methods for estimating various building energy system loads, It has demonstrated the use of machine learning for building energy purposes.The above literature reviewed in some of the recent works substantiates that the new age technologies like Blockchain, Internet of things and Machine learning has great potential in reducing energy consumption in buildings. But the challenge lies in exploring the characteristics that makes these computer technologies acceptable. To further explore the factors in each specific technology and make it more acceptable this research work is carried out.

1.2. Significance of the research

The energy usage in building often increases with passage of time. One of most evident cause for this high energy usage is: Buildings are highly efficient in operations and in energy consumption within first five years of usage. As the time passes over the years the building walls, Roof, windows and glazing, gradually deteriorate resulting in high energy consumption. Additionally, the equipment in the building like HVAC, pumps, Water heaters add to the inefficiencies over a period of time resulting in high energy consumption costing financial losses to building owners. This trend of high energy usage in buildings when attempted to optimise in conventional way meets with no much success. By using new age computer technologies as mentioned in this paper, the energy can be optimised and savings in energy with savings in utility bills can be achieved. The significance of the research is, the computer technologies in energy sector can save the exploitation of energy there by contributing to environment and climate, It also provides financial and monetary benefits to residential and commercial building owners.

2. Methodology

Best worst method (BWM) is one of the novel MCDM methods developed by Rezeai [6,7]. it is easy compare to other methods because of its fewer pairwise comparisons and reliable results [6]. Among different BWM methods Linear BWM is applied in this paper because of its ease of the comparisons, more reliability in results and also provides more consistent comparisons compared to AHP [5,6,8]. The stepwise procedure is as follows [5,6]:-

a) Establish the set of factors to be compared.

b) Now with the input from Expert decision makers, from the set of factors established, choose the most suitable candidate and choose the least suitable candidate for pairwise comparison.

c) Start pairwise comparison with the help of a scale from one to nine, Compare the most suited factor to all other factors from the set this comparison is called 'Best to other' comparison vector

$$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn}) \tag{1}$$

Here the a_{Bj} indicates the Preference of the most suitable factor B over factor j, it is understood that $a_{BB=1}$

d) Repeat the same comparison step , but now with the least suitable factor from the set, factors that is 'Worst to others', this comparison will arrive at vector

$$A_W = (a_{1w}, a_{2w}, \ldots a_{nw})^T \tag{2}$$

Here a_{jw} indicates the preference of factor j over the least preferable factor W, it is obvious that $a_{ww=1}$

e) The optimal weights are obtained

$$(w_1^*, w_2^*, \ldots w_n^*) \tag{3}$$

The weights in equation (3) can be arrived in such a way that the maximum absolute differences of $\{|w_3 - a_{Bj}w_j|, |w_3 - a_{Bj}w_j|\}$ for all j is minimized or equivalently:

$$\min in \max_i \{|w_3 - a_{Bj}w_j|, |w_3 - a_{Bj}w_j|\}$$

Such that

$$\sum_j W_j = 1$$

$$w_j \geqslant 0 \text{ for all j} \tag{4}$$

The problem in equation (4) is equal to the linear problem as follows

min ξ^L

Such that

$|w_B - a_{Bj}w_j| \leqslant \xi^L$ for all j

$$|W_j - a_{jw}w_w| \leqslant \xi^L \text{ for all } j \tag{5}$$

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$$\sum_j W_j = 1$$

$w_j \geq 0$ for all j

Solving the problem in equation (5) will achieve the optimal weights ($w^*_1, w^*_2, \ldots w^*_n$) and also the objective function to determine the value of ξ. The value of ξ will determine the consistency of the pairwise comparison matrix, the value of consistency ratio (CR) more closer to zero means better consistency and closer to 1 is considered as less consistent [6,7]. The consistency ration of all pairwise comparisons in this research work were checked and found to be less than one, thus proving that the pairwise comparison and decision taken in this paper are reliable and with uniform consistency.

3. Case empirical study

The factors that are presented here are collected from literature review of the recent works in emerging computer technologies in energy efficiency field, the table-1 in section 2 Literature review; presents the supporting evidence for the factors collected. An expert team of 12 members was constituted for consensus on the listed factors and consensus was obtained before proceeding with pairwise comparison. The expert team consist of 4 PhD-Professors from Academia with more than 15 years of experience in energy related field, four software professionals working in industry in energy related domain from past 10 years. Two software programming developers for energy efficiency in buildings with experience of 10 years. Two end users of the technology from past five years. All the experts who participated in Decision making and pairwise comparison had a minimum qualification of a bachelor's degree in related field.

The pairwise comparison of decision makers were averaged to one whole number to enter in the best worst method vectors. The steps explained in section are as follows;

a) With the help of Table 1 in literature a set of factors were established Table 2.

b) The pairwise comparison was accomplished with the input from expert team and by using equation (1) and equation (2)

c) The final weights of factors are obtained by applying equation (3) 4 and 5.

d) The value of ξ is checked for all set of pairwise comparison it is also mentioned in Table 3.

e) The consistency ratio for all pairwise comparison is checked from Table-2 and equation (6). It is found to be less than 1 hence all pairwise comparisons made are consistent.

$$C.R. = \frac{\xi}{consistencyindex} \quad (6)$$

Table 1
Supporting evidences in existing Literature.

Sl No	Computer Technologies	Supporting evidence
1	Blockchain, BC	[9–12,20]
2	Internet of Things, IOT	[11,13–15,20]
3	Machine Learning, ML	[16–20]

Table 2
Consistency Index.

Number of Factors	1	2	3	4	5	6	7	8	9
Consistency Index	0	0.44	1.00	1.63	2.3	3.00	3.73	4.47	5.23

4. Results and discussions

Table 3 shows that among the main factors Blockchain (BC) has achieved the highest rank followed by IOE and machine learning. Among the subfactors the top three sub factors are located in the first Main factor reaffirming that the blockchain is the most important main factor strengthened its position by adding top three subfactors to its profile. The top three subfactors are Real time execution (RE), Security (S) and Transparency (TS).

The second most important main factor is Internet of things (IOT) this has achieved second rank in main factors and it contains top three middle level ranks. The top three subfactors in IOE are its SMART(S) rank 4, Intelligence(I) rank 5 and Internet of Everything (IOE) rank 7.

Although machine learning is one of the most important emerging computer technologies in the field of energy efficiency in buildings it has taken the least ranking among the main factors and also its subfactors are least ranked among all subfactors. The top three subfactors are Accuracy in Data mining (AC) ranked 8, Predictability (PR) ranked 10 and Biomimicry (BM) ranked 12.

The analysis of ranks of all subfactors reveals that top three ranks are in first main factor that is in Blockchain, the least ranked subfactors are in main factor 3 that is machine learning. This makes the second main factor Internet of things (IOE) the second ranked factor.

5. Conclusion

The rise of various novel computer technologies have opened up opportunities to connect the virtual computer world with buildings and managing their day to day energy operations. If the importance and ranking is known, The factors could be prioritised to achieve the aim of energy efficiency in buildings. .From table 3 with reference to weights of the main factor in table 3 we can conclude that among the main factors block chain is the top most important and vital computer emerging technology to achieve energy efficiency in buildings. The second most emerging computer technology is Internet of things (IOE followed by Machine learning (ML). These three technologies are rated as the top most technologies in achieving building energy efficiency.

The top three factors that has made blockchain the topmost computer technology is Realtime execution (RE), Security (S)and Transparency (TS) followed by trackability (TR) and localised control (LC). These are the factors that has made the first main factor BC the rank 1 among all main factors.

The second top most main factor critically important for achieving energy efficiency in buildings is Internet of things (IOE) with the second top most position in weights. The subfactors that has made IOE second most important factor is SMART(S), Intelligent (I) and Internet of everything (IOE) followed by Huge data management (DM) and Adaptability (AD). The last most important main factor is Machine learning on rank 3 and the factors that make machine learning most important in energy efficiency in buildings are Accuracy, Predictability, Biomimicry followed by Automation and forecasting.

6. Limitation, further scope and managerial application

This research is a holistic approach towards the technologies that are still in the nascent stage. One of the limitations of this research is; as technology evolves day by day new factors could come into existence which may influence the subfactors presented in this paper to vary in ranking. It is also possible due to technological advancement popular technologies may face stiff competition with new emerging technologies to come. Hence the factors given

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Table 3
Rank and Weight of driving factors.

Sl No	Theme (ξ = 0.0888)	Factor	ξ	Local Weight	Global Weight	Rank
1	Blockchain, BC (W = 0.644)	Security(S)	0.1871	0.206	0.285	2
2		Real Time Execution (RE)		0.4335	0.279	1
3		Localised Control (LC)		0.0493	0.032	9
4		Trackability (TR)		0.1034	0.067	5
5		Transparency (TS)		0.2069	0.133	3
6	Internet of Things, IOT (W = 0.244)	SMART (SM)	0.244	0.3993	0.098	4
7		Intelligent(I)		0.2560	0.062	6
8		Huge data management (HD)		0.1024	0.025	11
9		Internet of Everything (IOE)		0.1706	0.042	7
10		Adaptability (AD)		0.0717	0.017	13
11	Machine Learning, ML (W = 0.111)	Biomimicry (BM)	0.083	0.1818	0.020	12
12		Predictability (PR)		0.2727	0.030	10
13		Forecasting (FR)		0.0909	0.010	15
14		Accuracy in data Mining (AC)		0.3636	0.040	8
15		Automation (AT)		0.0909	0.010	14

in this paper are a comparative analysis only for three technologies that is blockchain, IOE and Machine learning. If more technologies are added the subfactors may vary in ranking. The future scope of this research could be extended to repeat the same factors with different methodology such as DEMETAL to study the interrelations among factors. This paper analysis only three computer technologies, further more new computer technologies could be added to main factors and analysis could be repeated to get better picture.

The results of this research could be used to decide on a technology for practical application in energy efficiency market. Many energy Efficiency Apps and software developers can take the outcome of this research while developing software, programming an algorithm or developing Apps intended for energy efficiency. The factors can act as a guide for investment into a new technology for energy saving in buildings.

CRediT authorship contribution statement

Syed Shuibul Qarnain: Writing - original draft, Methodology. **S. Muthuvel:** Validation. **S. Bathrinath:** Conceptualization, Writing - original draft. **S. Saravanasankar:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Further Reading

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