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A comparative analysis on thermal performances of Conditioned and free running houses

(Case study in moderate climate of Babolsar, Iran)

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Abstract

There has long been a concern that evaluating building thermal performance on the basis of energy loads is inappropriate to achieve overall energy efficiency of houses, particularly passive houses, in temperate climates. Passive buildings designed to be free running may achieve better results in an appropriate evaluation system.

The main objective of this study is to investigate differences between thermal performances of houses in different operation modes. The paper illustrates a relationship between indicators of building performance in free running and conditioned modes. Simulation is used to compare the predicted performances of conditioned and free running houses, respectively on the basis of annual energy requirements (MJ/m^2) and Degree Discomfort Hours (DDH) in temperate climate of Babolsar, Iran. Despite a strong relationship between these two indicators, some significant differences become clear leading to a discussion of the persistent technical problems and issues, which are encountered when attempting to optimize an efficient architectural design. The result of this study persuades the architects to pay more attention to the process of building energy efficient design regarding to the building operation mod. Application of this result in the building labelling system can promote the passive building design which is an important step to achieve objectives of sustainable development.

Keywords: Thermal performance, Energy efficiency, Thermal comfort

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1. Introduction

The main objective of building thermal performance evaluation is improving design quality at the design stage. Design quality refers to the provision of pleasant indoor conditions for buildings occupants. Pleasant condition depends on many environmental parameters such as humidity, ventilation and temperature. Such a pleasant condition can be obtained by changing architectural design or consuming more energy. However, in the interest of sustainable development, efforts are needed to minimize energy consumption, and in response, building performance evaluation systems have been developed.

In response to the call for reducing energy demand in the building sector, House Energy Labelling/ Rating Schemes, as evaluation systems have been developed in order to promote energy efficient design. These systems offer a mean for comparing the energy efficiency of different houses by generally

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providing a standardized evaluation of a house’s existing energy efficiency, expected energy use cost and its potential for improvement. They differ in the range of energy end use categories covered, but commonly the basis of most programs has been the normalized energy requirement for space heating and cooling and sometimes water heating. However, relying on the control of energy consumption is not the only way to achieve energy efficiency in architectural design. These systems generally assume that a house with less energy usage is the most energy efficient house [1]. But, low energy use does not necessarily correlate with energy efficiency [2]. Energy minimization is related to the efficiency of appliances as much as it is to the fabric of the building [3]. It has been argued and demonstrated that a simple normalized energy based evaluation system is not sufficient to convey the credibility of an energy efficient design [3-7], and that this issue appears to be more critical when a house is specifically designed to be operated in free-running operation mode [8, 9]. This issue is discussed in other studies that investigated efficient architectural concepts [10-12]. Therefore thermal performance of an architectural design would be evaluated in free-running operation mode and on the basis of an index related to energy efficiency not energy usage. This subject is the cornerstone of this paper to which an index for evaluating thermal performance of free running building, and; a systematic method for the performance evaluation were developed. Although there are numerous researches for improving energy efficient buildings based on building energy performance evaluation such as [13-16] the comparative analysis reported in this paper is a distinctive clue towards energy efficient buildings design.

In architectural view, an ideal energy efficient building is a building which makes thermally comfortable indoor environment for its occupants without cooling/ heating energy load. This idea leads architects to focus on efficient free running buildings that would be assessed on the basis of thermal comfort. In developing an evaluation system for building thermal performances, the question of correlation between the performance of buildings in their free-running and conditioned modes arises. It was assumed that any specific method and technique employed to improve the thermal behaviour of free-running building would also enhance its behaviour in conditioned operation mode. However the preliminary comparative studies by the author demonstrated contradictory results [9, 17].

This paper using simulation program investigates thermal performances of dwellings in two different operation modes then uses regression analysis to show some relevant differences between an energy efficient design for a conditioned and a free running house.

2. Definition

Conditioned building: A building that is provided with an energy supply for heating/ cooling indoor environment to maintain its indoor condition within a defined comfort zone.

Free running building: A building that is naturally ventilated and does not use any mechanical equipment to maintain or improve its indoor thermal condition.

3. Evaluation of a building thermal performance

Effective evaluation of buildings thermal performance plays an important role towards the reduction of energy consumption for space heating and cooling. Building performance evaluation is an approach to the design and construction of a building [18, 19]. It deals with post- occupancy performance assessment for further building construction and renovation [18, 20] often by using simulation program in order to ensure the quality of a building during architectural design process.

Building performance is assessed by a numerical measure of an indicator. The typical performance indicator includes overall thermal transfer value, heating/cooling energy load and so on [14]. This indicator is just suitable for evaluating building thermal performance in conditioned operation mode. The indicator should be a value derived from a parameter that describes the state of building, thus two different indicators would be defined for evaluating a building thermal performances in different states (free running/ conditioned mode). The thermal quality of a building can be assessed in terms of annual energy requirements in its conditioned mode, or an aggregated annual thermal comfort condition in its free running mode. The latter is independent to building appliances and demonstrates the actual performance of the building; it address multiple aspects of efficiency in a particular architectural design[4].

It should be noted that thermal performance of a building vary depends on "occupancy scenarios. Ignoring occupancy diversity factors may result in misleading simulation results, in the process of a building evaluation system, and may introduce inefficiencies in the final equipment and system design [21]. Szokoly[22] argues that occupancy factors cannot be taken into account in an evaluation system because of their high variability; so that the building itself has to be assessed. In contrast, Olofsson et al [2] argue that if the evaluation system is to reflect the energy efficiency of an occupied building, the actual influence of the users has to be taken into account, for which an evaluation of users is required. The author in the previous studies introduced multiple occupancy scenarios for residential buildings [3] and demonstrated how these scenarios can change the result of a house evaluation system, then proposed a fuzzy method to integrate multiple occupancy scenarios into a building evaluation system such as HERS [23]. This study considers only one of those occupancy scenarios for simulations, in which houses are assumed to be occupied for 18 hours between (6 – 24) in their living zone and 6 hours (0- 6) in their bedroom zone.

3.1. Evaluation of house's thermal performance in free- running operation mode

A free running building can be evaluated on the basis of achieved thermal comfort. Fanger's comfort theory [24] is applied in some standards [25, 26] and various studies as a basis for aggregating temperature exceedance hours. However, the inapplicability of this model for free running buildings has been well documented [27-34]. A similar method, in which environmental and personal variables are included, needs to be developed for free running building assessment.

Degree Discomfort Hours (DDH) is a unit for measuring the extent to which the indoor temperature falls outside comfort boundaries. Many studies, conforming to the ASHRAE standard [35], consider 80% occupants' acceptability to determine the boundaries of comfort conditions. In this study, the bounds of comfort temperatures for free running buildings were determined based on an adaptive thermal comfort model [27, 35] for a more conservative 90% occupant acceptability.

$$T_{(N)} = 0.31\, T + 17.8 \qquad (1)$$

In which T is average monthly temperature

The boundaries of the comfort zone corresponding with 90 and 80% thermal acceptability are shown in Fig. 1 for the moderate climate of Babolsar. The temperature bounds for 90% acceptability were applied for the living zone. The lower temperature bound of the 90% acceptability band was pulled down for the Bed zone during the sleeping period (0 – 6 a.m.) because it is assumed that occupants will use a blanket if they feel cold.

Although the adaptive comfort model does not require humidity or air speed [35], one cannot ignore the effect of humidity in the sensation of temperature, particularly in a humid climate. The effect of humidity on Environmental Temperature (ET) was accounted for by employing the following simplified equation proposed by Szokolay [36].

$$T_{intercept} = T + 23\,(T - 14)^{8}\, HR_{T} \qquad (2)$$

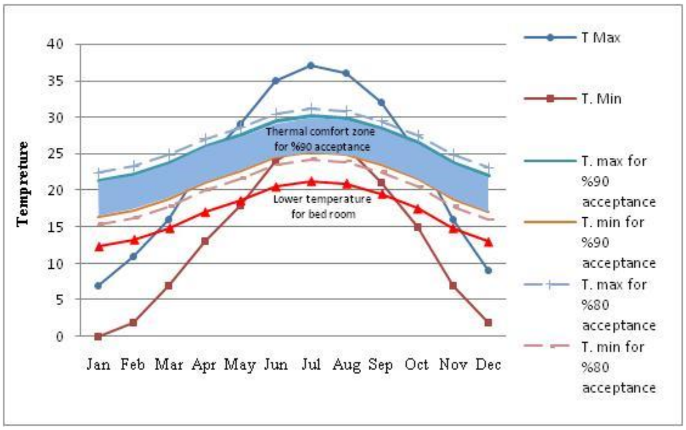

Fig.1 The boundaries of thermal neutrality comfort for the Babolsar Climate

Air movement through a house is a complex function of internal space arrangement and operable doors and windows. There is no suitable simplified tool available to investigate cross ventilation for free running buildings accurately. This study used Accurate software in which the potential beneficial use of natural ventilation is accounted in computing a building's annual energy requirement. The software use a factor related to the potential for physiological cooling in computing cooling energy requirements.

In Degree Discomfort Hours (DDH) concept, each discomfort hour has the effect being weighted by a factor equal to its 'distance' in degrees from the comfort range. It means the value of an hour 2°C above or below the comfort range is equal to the value of two hours with 1°C out of comfort range. For more accuracy in the calculation of the indoor comfort condition[3]., 'cooling degree hours' in winter and 'heating degree hours' in summer were removed from the aggregated annual degree discomfort hours.

3.2. Evaluation of house's thermal performance in conditioned operation mode

The performance of conditioned houses is generally indicated by normalized annual energy requirements (MJ/m^2). To predict annual energy requirements of houses in the conditioned operation mode, the notion of thermal comfort is implied in the thermostat settings. These thermostat settings indicate when heating and cooling is turned on in the computer simulations. Different thermostat strategies for discretionary heating and cooling of houses in temperate climate results in different prediction of energy requirements [37]. This study determined thermostat settings based on the description of thermal comfort in building national regulation in Iran, (number 19). Table 1 shows thermostat settings used in this study for the Babolsar in moderate climate of Iran. Heating temperature for bedrooms during midnight to 6 a.m. was set on 15^{o}C due to the assumption that occupants use blankets during sleeping time.

Table 1. Thermostat settings in conditioned houses for the Babolsar, moderate climate in Iran

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Zones	Heating temperature(ºC)	Cooling temperature(ºC)
Living	20	24
Bedroom	18	24

4. Simulation program

The software application used for the simulation in this study is AccuRate which has been validated using BESTTEST[38]. This software has the capability for analysing energy consumption and hourly temperatures of a free running building [39]. One of the main features of the software is its capability to consider the beneficial use of natural ventilation in computing cooling energy requirements. The benefit of suitable natural ventilation is a combination of mass transport cooling by volumetric air exchange when appropriate, and physiological cooling depending on a simplified model of internal air velocity related to regional wind speed and direction. Thus its output results for conditioned houses in terms of annual energy requirement are thought to be more reliable compared to results from other software which ignores the impact of natural ventilation in air-conditioned buildings. The AccuRate software is adapted for Australian climate, so for the purpose s of this study one of its determined weather data files was replaced by Babolsar weather data.

5. Modeling samples

It was impractical to take into account all different house typologies. This research focused on four typical houses constructed 15-20 years ago, single storey and double storey, with masonry wall construction and designed in Babolsar city, Iran. The general characteristics of these houses are shown in Table 2.

Table 2. General measurements of four typical houses

Typical house	Number of floors	Floor area (m^2)	External wall (m^2)	Window area (m^2)	Ceiling area (m^2)
Sample 1	1	110.56	109.5	25.8	110.56
Sample 2	1	124.32	119.9	19.84	124.32
Sample 3	2	171.43	137.6	26.9	102.1
Sample 4	2	204.96	178.68	39.2	98.8

A total of 214 samples, generated from the four typical houses, were simulated for analysis. The models were different from each other in terms of 17 variables which are determined in Table 3. Each model was simulated for two different house states, free running and conditioned operation mode. Thus the total number of simulation used in this study to a regression analysis is 428 simulations.

Table 3. House variables for simulations

House parameters	Variation of building parameters
Wall colour	Light, medium and dark colour (solar absorbance)
Wall insulation	R = 0, 1, 1.5, 2, 3 (m^2 K/W)

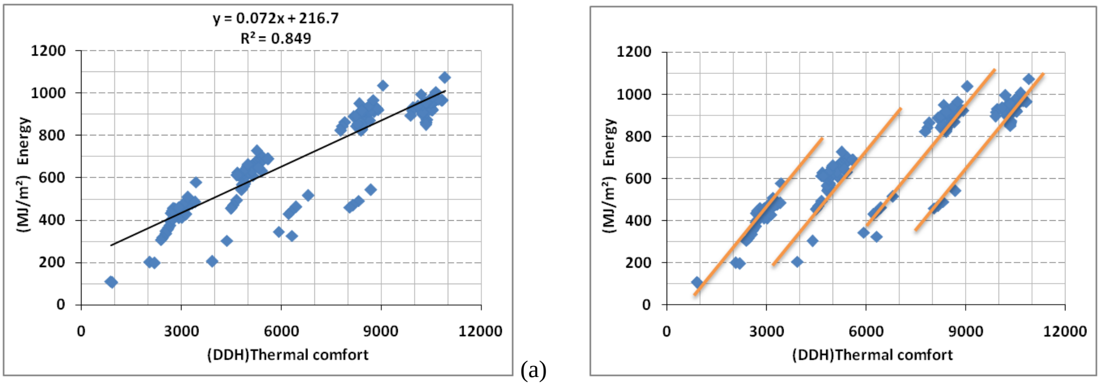
Ceiling insulation	R = 0, 1, 2, 3, 4 (m^2 K/W)
Floor insulation	R = 0, 1, 1.5, 2 (m^2 K/W)
Roof colour	Light, medium and dark colour (solar absorbance)
Eave width	0, 450, 600, 1000 mm
Orientation	0, 45, 90, 135, 180, 225, 270, 315 degrees
Glazing type	Single glazing: reflective, tone and clear Double glazing: clear and tone
Window covering	Open weave, closed weave, heavy drape and heavy drape + pelmet
Internal wall construction	Plasterboard, concrete block, brick plasterboard and cavity brick
Percentage of open able window	25%, 50% and 75%
Window eave width	0, 450, 600, 1000 mm
Percentage of open able window	25%, 50% and 75%
Infiltration	0, 1, 2, 5 (air change / hour)
Percentage of window to wall ratio (north and south sides)	0, 15%, 25%
Percentage of window to wall ratio (east and west sides)	0, 15%, 25%
House type	Single storey and double storey
Typical house	6 architectural house design

6. Results and discussion

Multiple regression analysis is typically used to identify those variables among a series of predictors that best predict the variation in a dependent variable, and to provide an estimate of how much variation in the dependent variable can be explained by variation in those predictor variables. Applications of regression are numerous in every field and occur in the building performance research whether based on experimental or simulated data [40-43]). In this study first a simple correlation is used to estimate the strength of the relationship between thermal performance of simulated houses in free running mode (as a independent variable) and their performance in the conditioned operation mode (as a dependent variable).

It should be noted that the data used for regression analysis in this study was generated from simulating typical houses located in Babolsar, moderate climate of Iran. Other locations and different house types such as apartment may yield different coefficient so the results cannot be generalized for all building types and climates. However the general trend observed in this study demonstrates a significant point that would be considered in an efficient architectural design, particularly in any building evaluation system.

Figure 2 illustrates the correlation between two indicators of houses thermal performances is positive and very strong (R^2 = 0.85). On a bivariate basis, that suggests that 85% of the variation in predicted energy requirements (MJ/m^2) can be explained statistically by its relation to DDH. The scatter diagram in Figure 2 demonstrates the strength of that relationship. Nevertheless, close observation of the points in Figure 2 suggests that there appear to be four separate, parallel linear clusters of points. Indeed, these four clusters refer to four house types. It is assumed that if the study includes more samples there would be one cluster group with more strong correlation between variables. More information on this regards comes in [44].



(a) (b)

Fig. 2. Correlation between indicators of thermal performance of simulated houses in different operation modes

Parallel correlation analyses were conducted for double storey and single storey houses. It was demonstrated that correlation relationship between variables in double storey houses was much clearer and stronger (R^2= 0.87) than single storey houses (R^2= 0.59). The strong correlation in double storey houses refers to architectural design of these houses. The annual thermal performance of a house strongly depends on the thermal performance of its living zone, because the majority of occupants' time is spent in this zone (about ¾ times). By disposing the living zone under the bed zone in double storey houses, the external surfaces area of the living zone in these house types is less than that in single storey houses. Therefore the free running performance of a single storey houses is more affected by outdoor climate than of a double storey house. This observation points to a key difference between the characteristic thermal performances of double storey and single storey houses and reflects on the reliability of any building evaluation system which assess all house types under a single similar condition. In the other word in an accurate evaluation system all house types cannot be evaluated under a similar condition, moreover techniques for improving energy efficiency of all house types are not similar.

Table 3 listed the parameters named "building fabric parameters" which can impact on a building thermal performance. Building designers tries to improve building energy efficiency by changing these parameters during design process. However the impact of each parameter on improving energy efficiency of buildings differs from others. This research use multivariate regression analysis to estimate how important these 17 variables are in improving the thermal performances of the typical houses in two states, for conditioned operation mode in terms of annual energy requirements (MJ/m^2) and for free running mode in terms of annual Degree Discomfort Hours (DDH).

Statistical analysis, using SPSS software, demonstrated that the 17 determined parameters do very well in explaining any variation in the thermal performance of houses in conditioned mode, where R^2= 0.82% in contrast, these predictors explain 0.72% of the variation in thermal performance of the houses in free running mode. A comparison between the results of other studies [17] and these results shows the effect of these parameters in predicting and controlling thermal performance of free running houses is less than that for conditioned houses in the moderate climate. Based on this observation, it can be concluded that

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the effect of environmental parameters and their interaction with building fabric parameters in improving thermal performance of free running houses is much important. The efficiency of a house in free running operation modes depends on environmental parameters and its occupant's behaviour [45] while in conditioned operation mode it depends on building fabric parameters and the efficiency of its appliances.

Table 4. Ranking of house parameters due to their relative importance on the houses' thermal performance

Houses in conditioned operation mode (MJ/m^2)				Houses in free running operation mode (DDH)			
Priority	Building parameters	Beta (β)	Sig	Priority	Building parameters	Beta (β)	Sig
1	House type	.697	.000	1	House type	.833	.000
2	Ceiling insulation	.460	.000	2	Typical houses	.362	.000
3	Typical houses	.170	.000	3	Ceiling insulation	.305	.000
4	Wall insulation	.095	.001	4	Wall colour	.094	.060
5	Infiltration	.081	.002	5	Infiltration	.051	.189
6	Roof colour	.038	.179	6	Wall insulation	.044	.285
7	Floor insulation	.037	.148	7	Percentage of open able window	.035	.376
8	Wall colour	.033	.324	8	Percentage of window to wall ratio (north and south sides)	.032	.436
9	Percentage of open able window	.031	.249	9	Glazing type	.030	.438
10	Eave width	.023	.369	10	Internal wall construction	.030	.459
11	Window eave width	.017	.516	11	Eave width	.029	.448
12	Glazing type	.012	.638	12	Window covering	.026	.550
13	Internal wall construction	.009	.734	13	Roof colour	.026	.539
14	Window covering	.009	.765	14	Window eave width	.026	.503
15	Percentage of window to wall ratio (east and west sides)	.003	.903	15	Orientation	.024	.547
16	Percentage of window to wall ratio (north and south sides)	.003	.920	16	Percentage of window to wall ratio (east and west sides)	.011	.774
17	Orientation	.000	.990	17	Floor insulation	.005	.892

The standardized coefficient correspond to beta weight (β) in multivariate regression analysis was applied to summarize the strength of the relationship between the design features and indicators of house thermal performance. A standardized coefficient was used in the interpretation, as each parameter was measured in different units. The standardized coefficients in a multiple regression analysis, in which house thermal performance defined as dependent variable and other 17 building fabric parameters defined as independent variables, evidence the strength of each parameter in a house thermal performance variation. Table 4 put these parameters in order (based on β) for houses in free running and conditioned operation modes. These two tables demonstrate the most important parameter in predicting thermal performance of houses is house type; the importance of other parameters vary depends on house operation mode. For instance floor insulation is clearly significant in conditioned mode analysis (number 7) but are well down the list (and far from statistical significant) in the free running analysis (number 17). Note that, this should not be taken to mean that floor insulation is irrelevant for free running houses only that the multivariate analyses have shown other factors to be more important. Other studies in these regard demonstrated that the effect of other building fabric parameters on a house thermal performance could be completely different for two different operation modes [9, 17]. This study evidenced the thermal performance of a house in conditioned operation mode can be improved (%5) by adding an insulation layer (R= 3 m^2 K/W) in the external wall while the same change degraded the thermal performance of that house in free running operation mode (Figure 3).

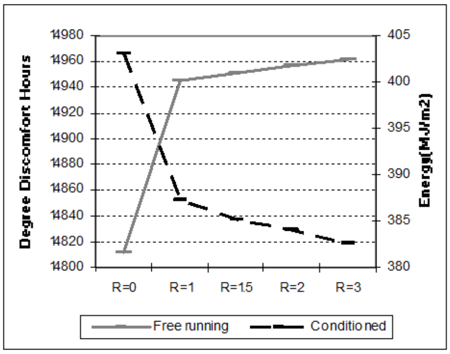

Fig.. 3. The effect of wall insulation in improving the annual performance of a house in two different operation modes[17]

Figure 4 illustrates a comparison between the orders of 17 defined parameters based on β coefficient for houses in two operation modes. It can be clearly seen that the order differs for two houses state, this means the significant and strength of parameters in improving thermal performances depends on house operation. The observation have implication that it cannot be assumed that a design for good predicted building performance in conditioned mode achieves good thermal performance in its free running mode. A design for conditioned building is reasonably related to the building envelope characteristics and fabric of the building. Ultimately it relates to those attributes that protect or isolate the building interior from the environmental loads, to maintain indoor thermal comfort conditions with minimum energy consumption to overcome those loads. The determinants of free running performance are more complex, as has long been implied by alternative terminology climatic responsive.

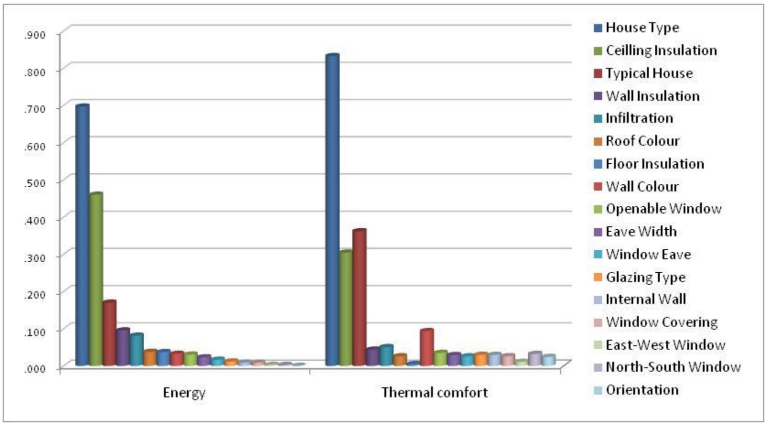

Fig. 4. A comparison between the strength of building fabric parameters on the thermal performance of typical houses in two different operation modes

7. Conclusion

Evaluating thermal performance of a building in design process can leads to construct an energy efficient building; however, depends on indices defined for assessment results may not be achieved in reality. Evaluating thermal performance of passive houses as a best sample of sustainable architecture is challenging in the current energy base evaluation systems. This study demonstrated that there is a need to develop a building performance evaluation system for free running building in which passive buildings can be assessed accurately. Since the criteria for enhancing the thermal behaviour of free running buildings can be shown to differ in a moderate climate from those for buildings operated in a conditioned mode, the former cannot be evaluated in an energy base evaluation system. The effects of building design features on the thermal performance of houses differ for different house operation modes therefore architects and building designed would pay more attention to the operation of buildings in the process of improving energy efficiency of buildings particularly in moderate climate in which free running houses should be promoted in response to the objectives of sustainable development. This paper highlighted that an efficient energy base building is not necessarily an efficient one in free running operation mode, so each of which designs requires new instruction and regulations.

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