

# Economic Feasibility and Technical Possibility of Net-Zero Energy Building in Tehran

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## Abstract

**Objectives:** The economic feasibility and technical possibility of net-zero energy building in Tehran is conducted numerically in this research. **Methods:** The methods of numerical study and simulation were applied to calculate the economic feasibility and technical possibility of net-zero energy building in Tehran. The numerical method is conducted using C++ programming and simulation did by Hourly Analysis Program, and Poly Sun software. The results of simulation and programming are compared and presented. **Findings:** Simulation shows that the majority of energy which is needed for cooling and heating could be declined using insulation and better material for making building. It is observed that gas and electricity consumption stood at 50970 kW and 14772 kW, respectively. After insulation, Gas demand and electricity consumption declined dramatically to reach 23270 kW and 10574.6 kW, respectively. The calculation of Trombe wall, ground Heat Pump, Photovoltaic is conducted using simulation and C++ programming. The results of programming and simulation show that Solar collector can produce 10209.8 kWh/ year, and ground source Heat pump produces 7009.5 kWh/ year, Photovoltaic panels produce 58.06% of the total electricity demand. This system can provide 74% of heating and cooling load and 68.3% of total energy which is consumed in the building. **Application and Improvement:** The reduction of energy consumption in building is very important these days and it is possible by insulation and Trombe wall. The majority of energy consumption can be provided using renewable resources in the building.

**Keywords:** Ground Source Heat Pump, Net-Zero Energy Building, Photovoltaic Panel

## 1. Introduction

Through these studies, scientists observed that the majority of final energy has been consumed by the building sector in the world. This means that Domestic, commercial and official sectors used one out of three or one quarter of energy, which is produced in the world. Some researchers are presented as is the following:

Nowadays, energy modelling has done with the using optimum HVAC energy system and building energy management. For example, in studies carried out<sup>1-3</sup>. Hourly building energy simulation program was applied to be evaluated heating and cooling load in the building and this study reduced the amount of energy demand in the buildings<sup>4</sup>. An optimization model was developed with the using

the hourly building energy simulation program to simulate the optimum thermal design of the building envelope<sup>5</sup>.

### List of symbols

$A_i$ internal contact area (m)	$R_s$ soil thermal resistance ( $m^2.K/w$ )
$A_o$ external contact area (m)	$T$ temperature (K)
$COP_c$ cooling coefficient of performance	$T_c$ ambient temperature (K)
$COP_h$ heating coefficient of performance	$T_d$ collector temperature (K)
$F_h$ part load factor	$T_e$ external temperature constructed the Trombe wall (k)

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$h_i$ internal convection heat transfer ( $w/m^2.K$ )	$T_{ewt,min}$ minimum design entering temperature (K)
$h_o$ external convection heat transfer ( $w/m^2.K$ )	$T_{g,min}$ minimum undisturbed ground temperature (K)
$H_z$ heat transfer coefficient of collector	$T_i$ indoor temperature (k)
$I$ radiation intensity	$T_{sa}$ radiation temperature of Trombe wall (K)
$I_g$ global solar irradiation	$U$ overall heat transfer coefficient ( $w/m^2.K$ )
$L_c$ length of cooling pipe (m)	$U_l$ heat loss coefficient ( $w/m^2.K$ )
$L_h$ length of hot pipe (m)	$V$ volumetric flow rate ( $m^3/s$ )
$Q$ thermal loads (kW)	$\alpha$ radiation coefficient
$q_{Hw}$ heat transfer ( $kWh/m^2.yr$ )	$\beta$ absorbing coefficient
$q_w$ heat flux (kW)	$\tau$ light transmittance coefficient
$R_p$ pipe thermal resistance ( $m^2.K/w$ )	

A numerical investigation of the optimum thermal design of building in Riyadh and Jeddah was conducted<sup>6</sup>.

A new simulation model was presented to investigate energy consumption in the building<sup>7</sup>. Metaheuristic simulation-EP (evolutionary programming) and non-linear programming was used to develop the evolutionary model<sup>7</sup>.

Two simulation software (TAS and TRNSYS) were applied to study solar system parameter<sup>8</sup>. The cost of the passive strategies with the using building material, window size and shading devices was assessed. TRNSYS software was used to perform a numerical investigation to optimize energy consumption in the building<sup>9</sup>. Through this investigation, GA and LCI models are employed to introduce the new simulation model in the building<sup>9</sup>.

People the indoor environment by opening windows; the cooling potential of opening windows; and the use of an adaptive algorithm for predicting window-opening behaviour for thermal simulation in ESP-r model was simulated<sup>10</sup>.

Co-simulation was suggested by the optimizing integrated HVAC system in the building. Based on this method, Building Performance Simulation (BPS) tool was designed this model employed<sup>12</sup>.

Potential of energy saving in hypermarket HVAC system is calculated by Urbikain M.K, whereas Energy Savings Estimation Model (ESEM) is employed<sup>12-14</sup>.

An integrated methodology is used to evaluate the energy performance of the building enclosures. This model is applied<sup>15-18</sup>.

The thermal performance is investigated by mass method in different kind of research. This method is gained<sup>19-21</sup>.

Building Performance Optimization (PBO) is used<sup>22</sup>. Building performance was simulated with Energy plus<sup>23</sup>.

New method introduced for energy modelling in the building is analysed<sup>24</sup>. Load and HVAC models were simulated by software<sup>25</sup>.

Now days, Load Match (LM) and Grid Interaction (GI) is applied to predict the performance of Net ZEB<sup>26-28</sup>.

Nowadays, TRAN Build models are used to simulate the Combined Heat and Power (CHP) and Domestic Hot Water (DHW). This model is used in different researches<sup>29-31</sup>.

Multiple-Linear Perceptron (MLP) was used to design a new model for chiller, pump, and fan and reheat device<sup>32</sup>. Energy consumption was optimized in the building<sup>32</sup>. New model with controllable and uncontrollable input and variable output was presented to predict the energy consumption<sup>32</sup>. Computational intelligence algorithms were developed to design a new model and the minimization of energy, consumed by the HVAC<sup>33</sup>. In fact, cooling and heating load is applied to compute the energy consumption in the building<sup>33</sup>. This investigation is sought to provide thermal comfort<sup>34</sup>.

Various methods, which gained to introduce a new model for calculating the Heating, Ventilation, and Air Conditioning (HVAC) energy system was analysed. TRCA Archetype Sustainable House (TRCA-ACH) was applied to conduct simulation on the HVAC system with the using a Ground Source Heat Pump (GSHP) in buildings in Ontario, Canada<sup>35</sup>.

Non- dominated Genetic Algorithm (NSGA-II) and multi objective optimization is applied to investigate interaction between the demand for energy in buildings and renewable energy<sup>36</sup>.

In this research it will be assumed that the total energy consumption in luxury family housing in Iran can be provided by using two renewable sources such as solar and geothermal energy. In this work we will also employ Tromble wall to reduce the demand for energy in this building? At first, energy demand for HVAC system and non- HVAC systems in standard condition will be simulated by HAP 4.5vs (Carrier Corporation, 2012). Through this simulation, Polysun 6.2.918113 (Vela Solaris, 2013)

is applied to simulate combined heat and power with the using ground source heat pump and solar energy. The solar collector, photovoltaic cells and Ground heat pump are used to be provided the energy which is needed for heating and cooling of building. The Photovoltaic system is designed to be traded electricity to national network and provide the energy for electrical gadgets and lighting for this building. The results might be used to improve efficiency of buildings and in decreasing air pollution from household, commercial, and public buildings.

## 2. Theory

The overall heat transfer coefficient was calculated by using heat loss and heating and cooling load<sup>37</sup>. As follows:

$$U = \frac{1}{\left( \frac{1}{h_i \cdot A_i} + R_1 + \dots + R_n + \frac{1}{h_o \cdot A_o} \right)} \quad (1)$$

The storage of heating water consumption is calculated, as follows:

$$Q = V \times 9.79 \times (T_2 - T_1) \quad (\text{kW}) \quad (2)$$

It should be mentioned that the amount of light and water consumption are calculated based on the standard of Ashrae<sup>38</sup> and the standard of ASPE<sup>39</sup>.

## 3. Case Study Description

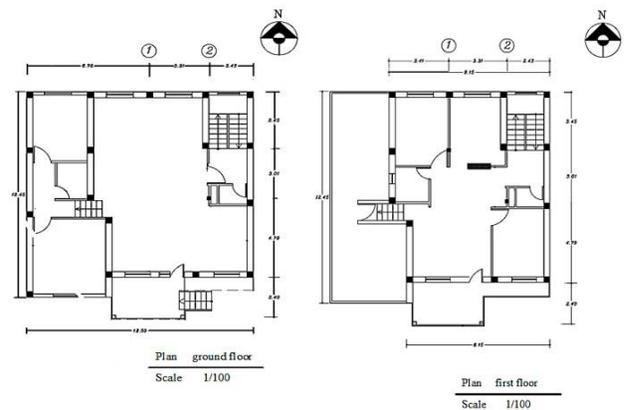
The characteristic of the building, including area, area of windows, electricity consumption and heating and cooling load is presented in Table 1.

**Table 1.** The characteristic of house

Items	Value
Building area (m <sup>2</sup> )	164.5
Area of windows (m <sup>2</sup> )	19.8
Electricity consumption (kWh)	14772
Heat and cooling loads (kWh)	65742
Hot water storage (liter)	3

Figure 1 shows that the building area and area of the windows are 164 m<sup>2</sup>, and 19.8 m<sup>2</sup>, respectively. The amount of lighting is 1.5 to 2 w/m<sup>2</sup>. The energy class is A. The average duration of lighting of lighting is considered

5 hr/day. As a result, the total electricity which is needed to be used for lighting is 4740 kWh/yr. The calculation shows that the electrical equipment needs 2409 kWh/yr and the average duration of using electrical gadgets is considered for 4 hr/day. The ground heat pump does not need to consume lots of electricity because it is water to water heat pump and it uses gravity and natural circulation. The model of the ground heat pump is BW113.2 made by SATAG Thermotechnik AG. It can produce 11.7 kW. In addition, electrical equipment and lighting system use 7149 kWh/yr. Based on the result, heating and cooling equipment used 65742 kWh/yr. In this project uses the ground heat pump, which does need to consume less electrical energy. In fact, it is a heat exchanger which used electricity for pumping only. Another point that should be mentioned is that heating and cooling loads and electrical consumption are computed by hourly analysis program 4.5 views, and the calculation is based on using thermal conductivity coefficient of building material, which is illustrated in Table 2. Moreover, indoor temperatures in winter and summer are assumed 21.2°C and 23°C, respectively.



**Figure 1.** The plan of building.

Besides, hot water consumption and hot water storage are calculated<sup>39</sup>. The water consumption, storage is 300 liter.

## 4. Method of Designing Net-Zero Energy Building

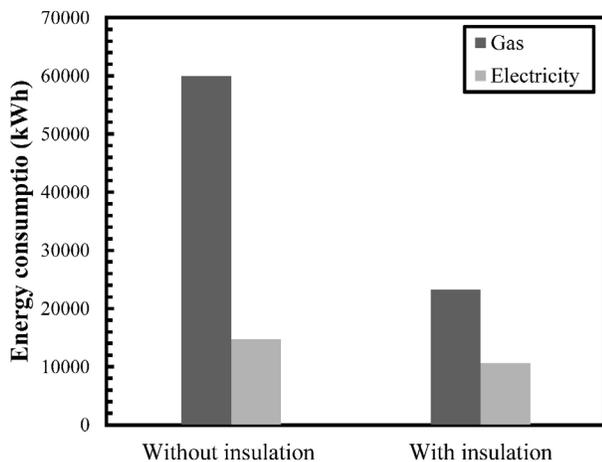
### 4.1 Passive Method

Comparison of the electricity and gas consumption before and after simulation is presented in Figure 2. It is

**Table 2.** The characteristic of building material

	Building material	Thickness (mm)	Heat transfer coefficient (W/m <sup>2</sup> . K)	Heat resistance (m <sup>2</sup> /w. k)
Roof	Plasterboard	25	0.5	0.05
	Polystyrene	40	0.058	0.689
	Roof brick	105	-	0.13
	Roof insulation	10	0.7	0.054
Wall	Plasterboard	25	0.5	0.05
	Polystyrene	40	0.058	0.689
	Common Brick	105	-	0.09
	Concrete	20	1.75	0.011

observed that gas and electricity consumption stood at 50970 kW and 14772 kW, respectively.



**Figure 2.** Comparison of the electricity and gas consumption before and after simulation.

After insulation, Gas demand and electricity consumption declined dramatically to reach 23270 kW and 10574.6 kW, respectively.

#### 4.1.1 Trombe Wall

The Trombe wall is constructed from heat absorbing material with thickness of 20 cm to 40 cm, and the surfaces of material, which has absorbed radiation heat, is dark color<sup>40</sup>. Furthermore, one or double glazing put in front of an exterior Trombe wall and distance between wall and glazing are 15 mm to 20mm. The cell temperature is calculated with using the ambient temperature and

radiation heat transfer, absorbing in the Trombe wall. That is evaluated by eq. (3):

$$T_{sa} = T_e + \frac{\alpha I_g}{h_c} \text{ (}^\circ\text{C)} \tag{3}$$

Heat flux transferred inside of the room is obtained from the Eq. (3):

$$q_w = U (T_i - T_{sa}) \text{ (w/ m}^2\text{)} \tag{4}$$

#### 4.1.2 Most of Lighting Bulb and Electric Device

The number of lighting bulbs are considered based on 1.5(w/ft<sup>2</sup>) to 2(w/ft<sup>2</sup>) and the rate of electricity consumptions are calculated in different part of building such as primary room, hall, dining room, ground floor, second floor room, and kitchen, (During lighting, device electricity and during of light, date by using electrical equipment is 4 or 5 in this building.

#### 4.2 Renewable Resources

The energy demand of building can be supplied with the using active solar method and renewable resource such as solar, geothermal. In this article, solar active method and ground source heat pump are applied to providing the energy demand. In addition, radiator with various temperature ranges between 60°C to 125° can be used in the ground source heat pump. Furthermore, cooling is feasible to be supplied by using reverse cycle of heating process. The efficiency of ground source heat pump is almost 70%. In addition, the Length of pipe achieves by Eq. (5) and (6)<sup>41</sup>:

$$L_h = q_{d,heat} \left[ \frac{\frac{(COP_h - 1)(R_p + R_s F_h)}{COP_h}}{T_{g,min} - T_{ewt,min}} \right] \quad (5)$$

$$L_c = q_{d,cool} \left[ \frac{\frac{(COP_c - 1)(R_p + R_s F_c)}{COP_c}}{T_{ewt,max} - T_{g,max}} \right] \quad (6)$$

This point should be mentioned that ground source heat pump is computed with C++ code. Furthermore, the length of the tube is considered 140 m, and it is placed vertically.

### 4.2.1 Solar Collector and Photovoltaic

The number of solar collectors is calculated by using the amounts of hot water consumption, and it is also shown in Table 3. Moreover, it is calculated by using the characteristic of solar collector glass and Hottle-Whillier equation<sup>42,43</sup>. As in following:

$$q_{HW} = \tau\beta I - U_L (T_d - T_c) \text{ (kWh/ m}^2 \cdot \text{yr)} \quad (7)$$

**Table 3.** The characteristic of building material

Item	W
400	1
1000	2
600	3
400	4

## 5. Result and Discussion

The solar collector manufacture is Shandong Linuo New Material Co., Ltd and the model of collector is LN-RG-WF-1.6/16-47-1500-A. The characteristics of the solar

collector are presented in Table 4. It is observed that the absorption coefficient and the light transmittance coefficient were 93%, and 91.6%, respectively. Once the temperature of the collectors is 50°C, and the area of solar collector placed is 31.5 m<sup>2</sup>. Overall heat loss coefficient of single-glazed collector is 1.98 w/m.k in winter. Then, overall heat loss coefficient of solar collector is calculated as 1.51 kWh/m<sup>2</sup>.

### The features of solar collector

Property	Float	Sheet lime	White
Iron-oxide content, percent (%)	0.12	0.12	0.01
Reflective index	1.52	1.52	1.5
Light transmittance (τ), percent (%)	84	84	91.6
Reflective loss, percent (%)	8.2-8	8.2-8	8
Absorption loss, percent (%)	8.0-13	8.0-13	under

The weather data is shown in Table 4. Then, the weather data and the characteristic of collectors are used to calculate the amount of radiation energy, which is absorbed by solar collectors on January 21<sup>st</sup>., the solar energy, which is absorbed on January 21<sup>st</sup>. Based on the results, the maximum of the solar energy is absorbed in 1 P.M.

The amount of solar energy, which is absorbed by solar collector in the year, is shown in Figure 3. By using 8 collectors, it is possible to absorb the wide range of solar radiation from 1.4 (kWh/m<sup>2</sup>. Day) to 5.7 (kWh/m<sup>2</sup>.Day). According to the hours of operation and the area of the collector which is 31.5 m<sup>2</sup>, the sum of energy, which is absorbed by solar collector, is about 10298 kWh/yr. As a result, the part of the heating and cooling loads are supplied because the energy, consumed in different part of the building, including heating water consumption, heating and cooling system, and hot water is about 23270.2 kWh/yr. Furthermore, this system can provide 51.3% of total thermal loads. This system can also provide 76.5%

**Table 4.** The weather data on January 21<sup>st</sup>

Hour	1	2	3	4	5	6	7	8	9	10	11	12
T(°C)	-0.93	-1.01	-1.11	-1.20	0.22	1.18	2.12	3.83	4.30	5.00	5.30	4.75
Hour	13	14	15	16	17	18	19	20	21	22	23	24
T(°C)	4.40	3.13	2.65	2.24	1.89	1.6	1.35	1.22	1.10	0.99	-0.88	-0.86

**Table 5.** The amount of energy is supplied by geothermal heat pump

Name	Unit	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow rate	l/h	3200	3200	3200	3200	0	0	0	0	0	0	0	3200	3200
Energy withdrawal of the ground heat pump	KWh	7009.5	1937.5	1010.6	533.8	0	0	0	0	0	0	0	1319.9	2207.7
Inflow temperature during operation	°C	1.5	1.5	2	2.4	0	0	0	0	0	0	0	1.9	1
Minimum value	°C	-1.6	-1.5	0.1	0.5	0	0	0	0	0	0	0	-0.1	-1.6
Maximum value	°C	17.8	17.6	15.1	12.4	0	0	0	0	0	0	0	17.8	15.4
Outflow temperature during operation	°C	3.4	3.3	3.9	4.3	0	0	0	0	0	0	0	3.7	2.8
Minimum value	°C	0.02	0.02	1.7	2.1	0	0	0	0	0	0	0	1.6	0.03
Maximum value	°C	9.8	9.1	9.3	9.8	0	0	0	0	0	0	0	9.6	8.3
Temperature difference	°C	-1.9	-1.9	-1.9	-1.9	0	0	0	0	0	0	0	-1.9	-1.8
Minimum value	°C	-5.6	-3.8	-4.8	-4.2	0	0	0	0	0	0	0	-4.9	-5.6
Maximum value	°C	15.5	15.5	11.4	6.7	0	0	0	0	0	0	0	11.4	12.7
Flow rate during operation	l/h	407.4	1322.5	754.1	355	0	0	0	0	0	0	0	922.5	1545.9
Specific power withdrawal	W/m	45	45.1	45.7	46.3	0	0	0	0	0	0	0	45.6	44

of hot water system. According to the Figure 3, 10764.4 kWh/yr of solar thermal energy is absorbed by using combined heat and power with ground heat pump and solar collectors. Furthermore, it can be observed that the amount of fuel or electricity consumption is supplied by this system, and it is about 3613.4 kWh.

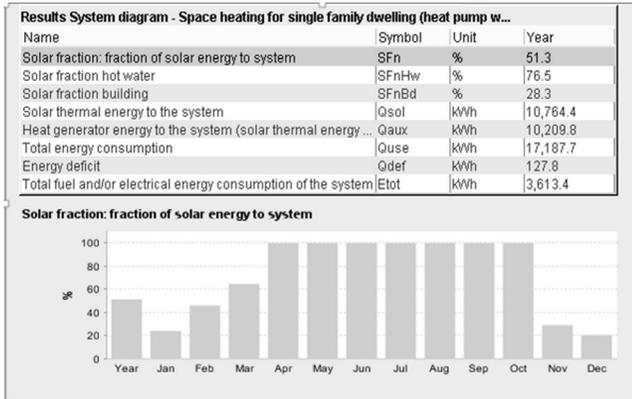


Figure 3. The amount of absorbed solar energy by collectors.

According the Table 5, ground source heat pump produces 7009.5 kWh/yr. In addition, this system just used for heating in winter as a result, solar energy and geothermal energy together generate 17764.4 kWh/yr. of the demand for energy in the building since energy demand is about 23270.2 kW. In addition, it can provide the most proportion of the thermal load, which is 76.34% of heating and hot water consumption.

The Photovoltaic Cells are built by Changzhou Nesl Solartech Co., Ltd. The name of photovoltaic cell is DJ-280P and the efficiency of cell is 0.14452. The area of Photovoltaic cells is 98.9 m<sup>2</sup>. According to Figure 4, Photovoltaic panel can produce 6140 kWh/yr. As a result, the portion of power consumption is provided by Photovoltaic panel. In addition, the amount of electricity demands for non - HVAC facilities and HVAC facility are 10574.6 kWh. This system can also provide 58.06% of total device electricity per year. This project is designed to be traded by the national network, so the electricity which is produced in summer is sold to the national network. The economic efficiency is calculated to improve the economic efficiency in this building.

Facility and HVAC facility are 10574.6kWh. Furthermore, this system can provide 58.06% of total device electricity year. To sum up, this system can provide 78% of heating and cooling energy and it can supply 69.83% of the total energy demand.

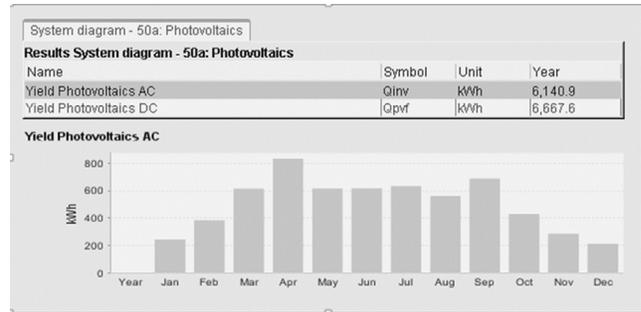


Figure 4. Electricity is produced by photovoltaic.

### 5.1 Economic Assessment

The investment and operating cost are presented in Table 6. Investing cost and operating cost are about 26146\$ and 818.33\$, respectively. However, these systems are led to reduce the energy cost in the year and the amount of saving money is about 4991.81\$ per year. According to Table 7, IRR is evaluated based on various inflation rates, including 3%, 10%, and 20%, and interest rate 17%. IRR obtains 0.03 and therefore payback time is 20.8 years.

Table 6. investment and operating cost

	Equipment	Price (\$)
Heating and Cooling System	Collector	1930
	Cost of installation	200
	Storage	2770
	Plumbing	6680
	Pump	340
	Heat Exchanger	145
Photovoltaic	Installation	165
	Inventor	4620
	Batteries	280
	Cells	8580
Insulation and Trombe Wall	Insulation and Trombe wall	290
	Glazing	146
Sum		26146

Table 7. Economic assessment

Economic assessment			
Inflation rate	NPV (\$)	IRR	Investment return
3%	-375000	---	---
10%	-175000	---	---

20%	108000	0.03	20.8
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## 6. Conclusion

In this research, the effect of using solar collector, photovoltaic panel, ground heat pump, and the Trombe wall was investigated theoretically in the house. The results may be summarized as follows:

1. Solar collector can produce 10209.8 kWh/ year, and 53.1% of total thermal load is provided by the solar collectors.
2. The ground source Heat pump produces 7009.5 kWh/ year, and it supplies 29.5% of total thermal load.
3. Photovoltaic panels produce 58.06% of the total electricity demand.
4. by using the Trombe wall and wall and roof insulation are decreased two out of three of heating and cooling loads.
5. This system can provide 74% of heating and cooling load and 68.3% of total energy which is consumed in the building.
6. IRR and payback time are 0.03 and 20.8 years, respectively.

According to the results, using the wall and roof insulation and renewable energy equipment has been provided the most proportion of the energy demand in the building. In fact, these provide 68.3% of total energy.

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