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Evaluation of the Effects of Building Materials on Human Health and Healthy Material Selection

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Abstract

According to the studies, people spend 90% of their life indoors and the amount of the harmfull gases in the buildings is higher than outdoor city pollution. They can cause diseases such as cancer, asthma, allergic reactions and much more. Building materials play a very important role to create ecologically and sustainably healthy environment. In order to construct a sustainable building which is friendly with the human and the environment, the building materials have to be chosen accordingly. The purpose of this study is to select the healthiest materials for the buildings, and to reduce indoor air pollution.

1. INTRODUCTION

The basic need of a human being is to lead a healthy life. "The building is an artificial environment made by human" [1]. Since people spend 90% of their life indoors, the main function of a building should be providing a healthy environment for its occupants. According to Akman, "The architectural structure respecting to the humanity and the environment should take place within the ecological cycles of the topography, not stand as a foreign object but be a part of it. In this context, the structure must be formed by the material of the topography and be able to return to the same topography when it completes its life" [2].

"There isn't such a material for every purpose in the land and it can't be used on a building as were in the environment. Natural resources that gone through artificial processes, is transformed into usefull building material" [1]. Buildings gain a great deal of the internal environmental characteristics through the external environment. Some building materials spread toxic gases at the moment they are extracted while most of them acquire this character when they are processed.

Building materials pollute indoor air quality for various reasons. These reasons may be derived from structure / content, application and the usage of the materials. Various human groups such as designers, manufacturers, supervisors take part of the construction of a building. Both the building and the user are negatively affected due to the harmfull substances used in the production of the materials, material selection without user requirements, financial inadequacy and the lack of the supervision as shown in Figure 1.

"Any negativity of the condtions will cause disturbing effects and the failure of the usage of the space" [3]. "Researchers have shown that, healthy circumstances cannot be maintained in the buildings that are newly developed or improved; furthermore, it is reported that 30% of the buildings caused "Sick Building Syndrome" [4].

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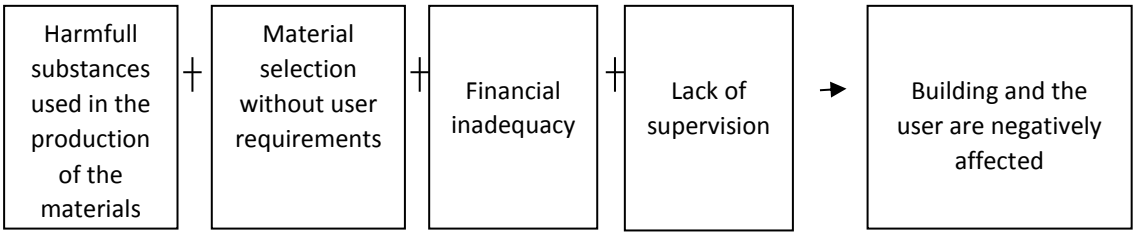

Figure 1. *Reasons that affect building and the user health*

It is clear to see the effects of finishing materials on human health on academic researches. For example some granite types used at the stairs or on the floor increase lung cancer risk because of the radon that they are released. The contents of urea and phenol formaldehyde adhesives of plywood, fibreboard, particle board and MDF cause respiratory track disorders. The Union of American Allergists stated that occurrence and spreading of an illness is 50 percent caused by indoor pollution; and 1/6 of patients, complaining from allergies consult doctors for medical treatment [5].

The purpose of this study is to evaluate the finishing materials with various propertiesthat affect human health and to find the most suitable and unsuitable materials for the indoor environment.

2. MATERIALS and METHODS

Arıoğlu method was used to evaluate the effect of building materials on human health [6]. This method has been developed as a result of analysis of many international evaluation methods including systems approach and Japanese Methodology developed by Japanese Building Research Institute. In this method, an assessment is made based on the expected performance requirements from the materials in the context of user requirements. “The aim of this method is to identify parameters and systematic pathways of selection of the building materials rationally to maintain user’s actions comfortably at the design stage and to select the best systematic pathway" [6].

At first, finishing materials which will be used in the method were determined. Natural and artificial (concrete) stone, wood, metal, polymer and terracotta based materials out of finishing materials were included to the evaluation. The sub-options of these materials have been chosen from the most used in the buildings and most effective ones to the human health. As a result;

- From natural and artificial (concrete) stone based materials; marble, some granites, onyx and concrete
- From wood-based materials; wood, plywood, particleboard and MDF
- From metal-based materials; steel, aluminum and lead;
- From polymer based materials; PVC, PP and HDPE;
- From terracotta based materials; ceramic, glass and brick

have been taken into consideration.

A figure which shows the properties of the selected materials was created. Profit-criterion table in Figure 2 was used to measure the spesifications of the usage values and alternation values of the alternatives with a scale factor. Interval scale provides the transformation of the values thet enables to measure the expected values of the alternatives and to provide the determination of the unit [6].

1	2	3	4	5
Useless	Less usefull	Usefull	Extra usefull	Most usefull

Figure 2. *Example of Profit-Criterion Table [6]*

After the profit-criterion table was created, the characteristics determined for each material were evaluated according to their significance level and importance coefficients were developed. At the end, the most

suitable and unsuitable materials for human health were found according to the importance coefficients and profit-criterion tables.

2.1. Natural/ Artificial Stone (Concrete) Based Materials

Some natural stones pose a threat to human health with harmfull gasses that they released. For example some types of granites cause respiratory tract diseases due to the radon gas they spread to the environment. However, not all natural stones are harmfull for human health. For example marble doesn't have any negative effects.

"In todays world, especially in ready mixed concrete plants, concrete is not produced without chemical additives. Chemical additives can improve the properties of concrete and can also have negative effects if used unconsciously" [7].

Properties of selected natural/artificial stone based materials are given in Table 1.The chosen properties have been decided as radioactivity, water absoption, odor decipol value, meeting user requirements, bending strength, abrassion strength, sound absoption, economy, source efficiency in Turkey, impact on human health, impact on the environment and reuse / recycle.

Materiality levels and comparison of natural and artificial (concrete) stone based materials are given in Table 2 and Table 3. According to the evaluation, marble can be seen as the most suitable material for human health.

Table 1. *Properties of the chosen natural/ artificial stone (concrete) based materials [8-19]*

PROPERTIES	**Marble**	**Granite**	**Onix**	**Concrete**
Radioactivity	-	4,7	-	2,3
Water absoption, max, %	0,4	0,75	0,6	9,1
Odor decipol value	In between	In between	In between	High
Meeting user requirements	In between	High	High	Low
Bending strength (MPa)-bearing, coating	870,25 (5,99)	1066,75 (7,36)	426,7 (2,94)	-
Abrassion strength	1	1,5	1	-
Sound absoption	0,01	-	-	0,01
Economy	In between	In between	Low	In between
Source efficiency in Turkey	In between	Low	In between	In between
Impact on human health	Low	High	In between	High
Impact on the environment	High	High	High	High
Reuse / recycle	In between	In between	In between	High
Profit/ criterion evaluation	**3.15**	**2.25**	**2.65**	**2.70**

Table 2. *Materiality levels and importance coefficients of the chosen natural/ artificial stone (concrete) based materials*

PROPERTIES	**MATERIALITY LEVELS %**			**IMPORTANCE COEFFICIENTS**
Radioactivity	MANDATORY	50	10	0,10
Meeting user requirements			5	0,05
Impact on human health			15	0,15
Impact on the environment			10	0,10
Reuse / recycle			10	0,10
Odor decipol value	PROTECTIVE	30	10	0,10
Sound absoption			5	0,05
Source efficiency in Turkey			15	0,15
Water absoption	OPTIONAL	20	5	0,05
Bending strength			5	0,05

Abrassion strength			5	0,05
Economy			5	0,05
	TOTAL	**100**	**%100**	**1.0**

Table 3. *Comparison of the chosen natural/ artificial stone (concrete) based materials*

	ALTERNATIVES							
Properties and Importance Coefficient	**Marble**		**Granite**		**Onix**		**Concrete**	
Radioactivity**x 0,10**	4	0,40	1	0,10	4	0,40	2	0,20
Meeting user requirements **x 0,05**	3	0,15	4	0,20	4	0,20	1	0,05
Impact on human health **x 0,15**	4	0,60	1	0,15	3	0,45	1	0,15
Impact on the environment **x 0,10**	1	0,10	1	0,10	1	0,10	2	0,20
Reuse / recycle**x 0,10**	3	0,30	3	0,30	2	0,20	4	0,40
Odor decipol value **x 0,10**	3	0,30	3	0,30	3	0,30	1	0,10
Sound absoption**x 0,05**	4	0,20	2	0,10	2	0,10	4	0,20
Source efficiency in Turkey **x 0,15**	3	0,45	2	0,30	3	0,45	5	0,75
Water absoption**x 0,05**	4	0,20	3	0,15	3	0,15	1	0,05
Bending strength**x 0,05**	3	0,15	4	0,20	2	0,10	5	0,25
Abrassion strength**x 0,05**	3	0,15	4	0,20	3	0,15	2	0,10
Economy**x 0,05**	3	0,15	3	0,15	1	0,05	5	0,25
TOTAL		**3,15**		**2,25**		**2,65**		**2,70**

2.2. Wood Based Materials

Wood is a natural and healthy material by nature. However, the wood tat was used in todays world threatens human health by the various harmful substances it contains."Adhesives and glues used in the production of artificial woods contain substances that cause toxic gases release" [1]. Plywood, particle board and MDF contains phenol formaldehyde and urea formaldehyde that creates poor indoor air quality. Properties of selected wood based materials are given in Table 4.The chosen properties have been decided as bending strength, odor decipol value, density of benzene toluene and xylene, water vapour diffusion resistance coefficient, fire resistance, economy, source efficiency at Turkey, formaldehyde emission, impact on human health, impact on the environment and reuse / recycle.

Table 4. *Properties of the chosen wood based materials[15,20-27]*

PROPERTIES	**Wood**	**Plywood**	**Particle board**	**MDF**
Meeting user requirements	High	In between	In between	In between
Bending strength (MPa)	73,24-129,67	60.29 (vertical) 64.99 (horizontal)	19.04 (vertical) 32.87 (horizontal)	24.70(vertical) 32.12 (horizontal)
Odor decipol value	Low	High	High	In between
Density of benzene toluene and xylene	Low	High	High	High
Water vapour diffusion resistance coefficient (μ)	40	50-400	20-360	20-50
Fire resistance	In between	Low	Low	Low
Economy	High	In between	In between	In between

Source efficiency in Turkey	High	In between	In between	In between
Formaldehyde emission (µg/m/hour)	Low	7-1100	100-200	210-2300
Impact on human health	Low	In between	In between	High
Impact on the environment	In between	High	High	High
Reuse / recycle	High	In between	In between	In between
Profit/ criterion evaluation	**3.75**	**2.20**	**2.15**	**2.80**

Materiality levels and comparison of wood based materials are given in Table 5 and Table 6. According to the evaluation, natural wood can be seen as the most suitable material for human health.

Table 5. *Materiality levels and importance coefficients of the chosen wood based materials*

PROPERTIES	**MATERIALITY LEVELS %**			**IMPORTANCE COEFFICIENTS**
Formaldehyde emission	MANDATORY	50	10	0,10
Meeting user requirements			5	0,05
Impact on human health			15	0,15
Impact on the environment			10	0,10
Reuse / recycle			10	0,10
Odor decipol value	PROTECTIVE	30	10	0,10
Fire resistance			5	0,05
Source efficiency in Turkey			10	0,10
Density of benzene toluene and xylene			5	0,05
Bending strength	OPTIONAL	20	5	0,05
Water vapour diffusion resistance coefficient			5	0,05
Economy			10	0,10
	TOTAL	**100**	**%100**	**1.0**

Table 6. *Comparison of the chosen wood based materials*

	ALTERNATIVES							
Properties and Importance Coefficient	**Wood**		**Plywood**		**Particle board**		**MDF**	
Formaldehyde emission**x 0,10**	5	0,50	1	0,10	3	0,30	4	0,40
Meeting user requirements **x 0,05**	5	0,25	2	0,10	4	0,20	4	0,20
Impact on human health **x 0,15**	5	0,75	1	0,15	1	0,15	2	0,30
Impact on the environment **x 0,10**	3	0,30	2	0,20	2	0,20	2	0,20
Reuse / recycle**x 0,10**	4	0,40	3	0,30	2	0,20	2	0,20
Odor decipol value**x 0,10**	2	0,20	1	0,10	1	0,10	3	0,30
Fire resistance**x 0,05**	3	0,15	3	0,15	3	0,15	4	0,20
Source efficiency in Turkey **x 0,10**	4	0,40	3	0,30	3	0,30	3	0,30
Density of benzene toluene and xylene**x 0,05**	4	0,20	1	0,05	1	0,05	2	0,10
Bending strength**x 0,05**	4	0,20	5	0,25	1	0,05	3	0,15
Water vapour diffusion resistance coefficient **x 0,05**	4	0,20	4	0,20	3	0,15	1	0,05
Economy**x 0,10**	2	0,20	3	0,30	3	0,30	4	0,40
TOTAL		**3,75**		**2,20**		**2,15**		**2,80**

2.3. Metal Based Materials

Lead is used as a dye raw material and effects human health very quickly. Aluminium which is used as facade claddings, partition walls, fabric dyes cause lung diseases and alzheimer. Steel is a metal that is very difficult to extract from the earth's crust.

Properties of selected metal based materials are given in Table 7. The chosen properties have been decided as particulate matter retention, odor decipol value, yield strength, electroclimatic pollution, meeting user requirements, fire resistance, melting temperature, economy, source efficiency in Turkey, impact on human health, impact on the environment and reuse / recycle.

Materiality levels and comparison of metal based materials are given in Table 8 and Table 9. According to the evaluation, aluminium can be seen as the most suitable material for human health.

Table 7. *Properties of the chosen metal based materials [1,15,28-30]*

PROPERTIES	**Steel**	**Aluminium**	**Lead**
Particulate matter retention	In between	High	High
Odor decipol value	In between	In between	In between
Yield strength (MPa)	High	In between	Low
Electroclimatic pollution	High	In between	High
Meeting user requirements	Low	High	High
Fire resistance	High	In between	Low
Melting temperature (energy) (°C)	High	In between	Low
Economy	In between	Low	High
Source efficiency in Turkey	In between	In between	In between
Impact on human health	In between	In between	High
Impact on the environment	High	High	High
Reuse / recycle	In between	High	High
Profit/ criterion evaluation	**2,65**	**2,80**	**2,15**

Table 8. *Materiality levels and importance coefficients of the chosen metal based materials*

PROPERTIES	**MATERIALITY LEVELS %**			**IMPORTANCE COEFFICIENTS**
Electroclimatic pollution	MANDATORY	50	10	0,10
Meeting user requirements			5	0,05
Impact on human health			15	0,15
Impact on the environment			10	0,10
Reuse / recycle			10	0,10
Odor decipol value	PROTECTIVE	30	10	0,10
Fire resistance			5	0,05
Source efficiency in Turkey			10	0,10
Particulate matter retention			5	0,05
Melting temperature	OPTIONAL	20	5	0,05
Yield strength			5	0,05
Economy			10	0,10
	TOTAL	**100**	**%100**	**1.0**

Table 9. *Comparison of the chosen metal based materials*

	ALTERNATIVES					
Properties and Importance Coefficient	**Steel**		**Aluminium**		**Lead**	
Electroclimatic pollution**x 0,10**	1	0,10	3	0,30	2	0,20
Meeting user requirements **x 0,05**	2	0,10	3	0,15	4	0,20
Impact on human health **x 0,15**	2	0,30	2	0,30	1	0,15
Impact on the environment **x 0,10**	1	0,10	1	0,10	1	0,10
Reuse / recycle**x 0,10**	3	0,30	5	0,50	4	0,40
Odor decipol value **x 0,10**	3	0,30	3	0,30	3	0,30
Fire resistance**x 0,05**	4	0,20	3	0,15	1	0,05
Source efficiency in Turkey **x 0,10**	3	0,30	3	0,30	3	0,30
Particulate matter retention**x 0,05**	3	0,15	2	0,10	1	0,05

Melting temperature**x 0,05**	1	0,05	3	0,15	5	0,25
Yield strength**x 0,05**	5	0,25	3	0,15	1	0,05
Economy**x 0,10**	5	0,50	3	0,30	1	0,10
TOTAL		**2,65**		**2,80**		**2,15**

2.4. Polymer Based Materials

"According to Greenpeace UK's 1996 report, Vinyl chloride, one of the building blocks of PVC, has been reported to cause various types of cancer, growth in the liver, formation of lung and brain tumors, especially breakdown in the male reproduction system" [6].

Properties of selected polymer based materials are given in Table 10. The chosen properties have been decided as meeting user requirements, melting temperature, thermal conductance, radioactivity, water absorption, bending strength, asbestos ratio, economy, source efficiency in Turkey, impact on human health, impact on the environment and reuse / recycle.

Materiality levels and comparison of polymer based materials are given in Table 11 and Table 12. According to the evaluation, PP can be seen as the most suitable material for human health.

Table 10. *Properties of the chosen polymer based materials [6,25,31-36]*

PROPERTIES	**PVC**	**PP**	**HDPE**
Meeting user requirements	High	In between	In between
Melting temperature (° C)	140-190	200-280	125-135
Thermal conductance (kcal/mh ºc)	0.14	0.26	0.42-0.51
Radioactivity	High	Low	In between
Water absorption	0.02-0.6	0.01-0.03	<0.01
Bending strength (kg/cm^2)	200-1100	450-560	217-386
Asbestos ratio	High	In between	In between
Economy	Low	High	In between
Source efficiency in Turkey	In between	In between	In between
Impact on human health	High	In between	In between
Impact on the environment	High	In between	In between
Reuse / recycle	High	High	In between
Profit/ criterion evaluation	**2,45**	**3,25**	**2,85**

Table 11. *Materiality levels and importance coefficients of the chosen polymer based materials*

PROPERTIES	**MATERIALITY LEVELS %**			**IMPORTANCE COEFFICIENTS**
Radioactivity	MANDATORY	50	10	0,10
Meeting user requirements			5	0,05
Impact on human health			15	0,15
Impact on the environment			10	0,10
Reuse / recycle			10	0,10
Source efficiency in Turkey	PROTECTIVE	30	10	0,10
Asbestos ratio			15	0,15
Economy			5	0,05
Melting temperature	OPTIONAL	20	5	0,05
Water absorption			5	0,05
Bending strength			5	0,05
Thermal conductance			5	0,05
	TOTAL	**100**	**%100**	**1.0**

Table 12. *Comparison of the chosen polymer based materials.*

	ALTERNATIVES					
Properties and Importance Coefficient	PVC		PP		HDPE	
Radioactivity**x 0,10**	2	0,20	4	0,40	3	0,30
Meeting user requirements **x 0,05**	4	0,20	3	0,15	3	0,15
Impact on human health **x 0,15**	2	0,30	3	0,45	3	0,45
Impact on the environment **x 0,10**	2	0,20	3	0,30	3	0,30
Reuse / recycle**x 0,10**	4	0,40	4	0,40	3	0,30
Source efficiency in Turkey **x 0,10**	3	0,10	3	0,10	3	0,10
Asbestos ratio**x 0,15**	2	0,30	3	0,45	3	0,45
Economy**x 0,05**	4	0,20	2	0,10	3	0,15
Melting temperature **x 0,05**	1	0,05	4	0,20	2	0,10
Water absorption**x 0,05**	4	0,20	5	0,25	5	0,25
Bending strength**x 0,05**	2	0,10	5	0,25	4	0,20
Thermal conductance **x 0,05**	4	0,20	4	0,20	2	0,10
TOTAL		**2,45**		**3,25**		**2,85**

2.5. Terracotta Based Materials

Clay is defined as an abound material in the nature. It becomes soft and can be formed easily when it is wet. Processes such as drying, crumbling, mixing of raw materials during the preparation of clay cause dust formation. Ceramic from terracotta based materials causes allergic reactions due to the adhesives it contains.

Properties of selected terracotta based materials are given in Table 13. The chosen properties have been decided as meeting user requirements, melting temperature, thermal conductance, moisture retention, rupture strength, porosity, odor decipol value, economy, source efficiency in Turkey, impact on human health, impact on the environment and reuse / recycle.

Materiality levels and comparison of terracotta based materials are given in Table 14 and Table 15. According to the evaluation, glass can be seen as the most suitable material for human health.

Table 13 : *Properties of the chosen terracotta based materials [1,17,37-44]*

PROPERTIES	**Ceramic**	**Glass**	**Brick**
Meeting user requirements	High	High	In between
Melting temperature (° C)	-	1500-1713	4000-2200
Thermal conductance (W/moC)	In between	In between	Low
Moisture retention	High	Low	In between
Rupture strength(MPa)	-	27	30-45
Porosity (%)	Low	Low	22-24
Odor decipol value	In between	Low	In between
Economy	In between	In between	High
Source efficiency in Turkey	High	High	High
Impact on human health	In between	Low	Low
Impact on the environment	Low	In between	Az
Reuse / recycle	High	High	High
Profit/ criterion evaluation	**3,15**	**3,80**	**3,35**

Table 14. *Materiality levels and importance coefficients of the chosen terracotta based materials*

PROPERTIES	**MATERIALITY LEVELS%**			**IMPORTANCE COEFFICIENTS**
Meeting user requirements	MANDATORY	50	10	0,10
Impact on human health			15	0,15
Impact on the environment			10	0,10
Reuse / recycle			10	0,10
Moisture retention			5	0,05
Source efficiency in Turkey	PROTECTIVE	30	10	0,10
Odor decipol value			15	0,15
Economy			5	0,05
Melting temperature	OPTIONAL	20	5	0,05
Porosity			5	0,05
Rupture strength			5	0,05
Thermal conductance			5	0,05
	TOTAL	**100**	**%100**	**1.0**

Table 15. *Comparison of the chosen terracotta based materials*

	ALTERNATIVES					
Properties andImportance Coefficient	**Ceramic**		**Glass**		**Brick**	
Meeting user requirements**x 0,10**	4	0,40	4	0,40	3	0,30
Impact on human health**x 0,15**	3	0,45	4	0,60	4	0,60
Impact on the environment**x 0,10**	3	0,30	2	0,20	3	0,30
Reuse / recycle**x 0,10**	4	0,40	4	0,40	4	0,40
Moisture retention**x 0,05**	2	0,10	5	0,25	3	0,15
Source efficiency in Turkey**x 0,10**	4	0,40	4	0,40	4	0,40
Odor decipol value**x 0,15**	3	0,45	4	0,60	3	0,45
Economy**x 0,05**	3	0,15	3	0,15	4	0,20
Melting temperature**x 0,05**	2	0,10	4	0,20	3	0,15
Porosity**x 0,05**	5	0,25	5	0,25	2	0,10
Rupture strength**x 0,05**	1	0,05	3	0,15	2	0,10
Thermal conductance **x 0,05**	2	0,10	4	0,20	4	0,20
TOTAL		**3,15**		**3,80**		**3,35**

3. RESULTS AND DISCUSSION

Selected natural and artificial (concrete) stone based materials, wood based materials, metal based materials, polymer based materials and terracotta based materials were compared according to various properties that affect human health. Selected properties for each material are classified according to materiality levels and quantified with importance coefficients. The most suitable /unsitable materials can be seen in Table 16.

Table 16: *The most suitable/ unsuitable materials for human health*

Materials	**Most suitable for human health**	**Most unsuitable for human health**
Natural and artificial stone (concrete) based materials	Marble	Some granites
Wood based materials	Wood	Particle board
Metal based materials	Aluminium	Lead
Polymer based materials	PP	PVC
Terracotta based materials	Glass	Ceramic

Evaluation of the materials was made according to Arıoğlu Method [6]. As seen on table 16, the most suitable materials for human health were determined as; marble fromnatural and artificial (concrete) stone based materials, natural wood fromwood based materials, aluminium frommetal based materials, polypropilene frompolymer based materials and glass fromterracotta based materials. The most unsuitable materials for human health were determined as; some granites from natural and artificial (concrete) stone based materials, particle board from wood based materials, lead from metal based materials, polyvinyl chloride from polymer based materials and ceramic from terracotta based materials.

For healthy environments, material properties should first be examined. The most suitable materials for human health like natural materials should be preferred. Life cycle of the materials should be considered. Material supervision shouldn't be optional but mandatory. Indoors should be ventilated as needed and materials which release radon, asbestos and formaldehyde shouldn't be used as much as possible.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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