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Araştırma Makalesi / Research Article

An Overview to Reducing Environmental Impacts with Material Selection in Building Vertical Envelope and Discussion Material Selection Guidelines for Turkey

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Abstract

The inefficient use of resources, increased consumption of fossil fuels, urbanization, and the resultant rise in building production have significantly escalated the environmental impacts of buildings in recent years. Material selection and the consideration of the life-cycle performance of materials are fundamental to ensuring sustainability. A substantial portion of a building's environmental impact is attributed to the materials utilized in its construction. Numerous studies indicate that material selection profoundly affects energy consumption and environmental impacts. Various methods and models exist for material selection. This study systematically summarizes material selection approaches from different research studies and discusses their applicability in Turkey. The findings reveal that material selection is a complex issue that should be considered from a life-cycle perspective. Although developing a comprehensive material selection method is challenging, its implementation is constrained by factors such as lack of data and standards. Consequently, considering material selection criteria is not yet feasible for Turkey. Nonetheless, research in this field is ongoing.

Keywords: *Building Material Selection, Life Cycle Assesment, Environmental Impact*

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Çevresel Etkilerin Azaltılması için Bina Düşey Kabuğundaki Malzemelerin Seçim Ölçütlerine Genel Bir Bakış ve Malzeme Seçim Ölçütlerinin Türkiye'de Uygulanabilirliğinin Tartışılması

Öz

Kaynakların verimsiz kullanılması, fosil yakıt tüketimindeki artış, kentleşme ve buna bağlı gerçekleşen bina üretimi binalardan kaynaklı çevresel etkilerin son yıllarda hızla artmasına neden olmuştur. Malzeme seçimi ve malzemelerin yaşam dönemi performansının dikkate alınması sürdürülebilirliği sağlamanın temel unsurlarından biridir. Binaların çevre üzerindeki büyük miktardaki etkisi, binada kullanılan yapı malzemelerine dayanmaktadır. Birçok çalışma malzeme seçiminin enerji tüketimi ve çevresel etkiler üzerinde büyük etkisi olduğunu göstermektedir. Farklı malzeme seçim yöntemleri ve modelleri bulunmaktadır. Bu çalışmada, farklı çalışmalardan sistematik bir yaklaşımla materyal seçim yaklaşımları özetlenmiş ve yaklaşımların Türkiye'de uygunlabilirliği ele alınmıştır. Çalışma, malzeme seçiminin karmaşık bir problem olduğunu ve malzeme seçiminin yaşam döngüsü perspektifinden ele alınması gerektiğini ortaya koymaktadır. Malzeme seçim yönteminin geliştirilmesi karmaşık bir sorun olmasıyla birlikte, uygulanması da bazı kısıtlardan dolayı sınırlı olarak gerçekleşebilmektedir. Malzeme seçim ölçütlerinin dikkate alınarak uygulanması Türkiye açısından veri veya standart eksikliği gibi nedenlerden dolayı henüz uygulanabilir değildir. Ancak bu alandaki çalışmaların devam ettiği bilinmektedir.

Anahtar Kelimeler: *Yapı Malzemesi Seçimi, Yaşam Döngüsü Değerlendirmesi, Çevresel Etki*

1. Introduction

Materials, energy and water are the three main resources required to construct and run buildings. Materials and energy are consumed at a faster rate than they are being produced. High level of consumption in today's world brings some serious problems which are caused by consumption. According to World Watch Institute report construction industry has consumed % 50 of resources, % 16 of water resources and % 40 of energy (Roodman and Nessen, 1995). In addition, half of the world's waste generation belongs to construction industry. In a building's life cycle %10-20 of environmental impact is formed by building materials. Therefore, materials selection' importance has risen in construction sector. In energy efficient building design, material and energy consumption are the key factors. Especially in built environment, material selection for building vertical envelope can be the most important factor. Some factors such as building shape, form and orientation sometimes are limited to design in built environment. In a building, vertical envelope materials have the largest volume in whole building materials. Building vertical envelope has also largest surface than other building components.

Material selection is an important problem, which affect buildings comfort level, environmental impact and energy consumption directly. The study has three major aims. Firstly, have an overview on reducing environmental impacts with material selection in building vertical envelope. Building material selection is a huge and complex subject. The building envelope, due to its extensive surface area, constitutes the component that consumes the greatest amount of materials within a building. Consequently, the selection of materials for the building envelope significantly influences the environmental impact associated with the utilization of building materials. Therefore, study is limited with building vertical envelope because of its effects on buildings energy consumption and environmental impact. Secondly, summarizing criteria for material selection in building vertical envelope to reducing environmental impacts. The last aim is to discuss criteria from point of applicability view and applicability for Turkey. An introductory study try to be done for building vertical envelope material selection which reduce environmental impact from life cycle view.

2. Material and Methods

In the study, building material selection criteria were taken from a life cycle perspective in order to have a comprehensive perspective. Energy consumption and environmental impacts caused by building materials during the production, use and disposal stages are explained in this section. Literature review was used to determine building material selection criteria.

2.1 Material selection for building vertical envelope impact's on energy consumption and environment

Reducing environmental impacts from building depends on reducing three main flows, which are material, energy and water, in building (Yeang, 2008, Kibert, 2013, Mehta and Prowal, 2013). According to US Green Building Council (USGBC) building materials choices are fundamental to achieving success in sustainable design (LEED, 2024). As I stated before material selection for building vertical envelope is a key factor in built environment to reducing energy consumption. Material's thermal properties in building vertical envelope affect building's operational energy consumption widely. Moreover, amount of materials in vertical envelope is more than other components so; embodied energy of building envelope is higher than other building components. A small literature overview has done for understanding relationship between material selection, energy consumption and their effects on environment. In this context master thesis, articles and proceedings, which are given in the references, were examined.

Zhou et al., (2023) have made a research which conducts a critical review to identify design variables affecting the environmental impacts of buildings at three design stages during the design processes. The study show that reveal that eight design variables in early design stages... have an impact on a building's life-cycle environmental impacts (Zhou, et al., 2023). In detailed design stages, there are four kinds of design variables such as finishing materials linked with the environmental impacts of a building (Zhou et al., 2023).

2.2 Material selection impact on energy consumption

In Carol Monticelli and others study, a single family house and a residential block with different vertical envelope alternatives has compared in building life cycle term according to energy consumption (Monicelli et al., 2011). All vertical envelope alternatives are in different thickness and materials but all have same thermal resistance. Alternatives are a) external thermal insulation render system on single leaf brickwork cavity wall, b) cement rendered lightweight brickwork outer leaf, insulation, gypsum rendered brickwork inner leaf; c) dense solid brickwork outer leaf, insulation, gypsum rendered brickwork inner leaf; d) ventilated wall, an external thermal insulation brick masonry wall externally covered in brick hollow flat blocks, and assembled by means of suspension devices and mechanical style fixings; e) single leaf brickwork cavity wall with cement rendering; f) Aluminum cladding and insulation layer indoor side. Envelope alternatives has compared according to embodied energy and operational energy consumption. Energy calculations have done according to ISO 13.790 standards and English data has used for embodied energy calculations (ISO, 13790). Material's effects on energy consumption can be seen from table clearly. Envelope alternative 'b' has lowest embodied energy amount but it has highest operational energy consumption amount. On the contrary, alternative 'f' has the highest embodied energy amount but it has lowest operational energy consumption amount. Alternative 'f' has aluminum cladding, as far as we know from literature aluminum is one of the highest embodied energy need materials. Therefore alternative 'f' has the highest embodied energy need even if it has lowest operational energy consumption amount. Another result taken from the table which is quite important is about maintenance energy need. There is a direct relationship between embodied energy and maintenance energy need. Alternative which has lowest embodied energy amount (b) has also lowest maintenance energy need. Aluminum cladding envelope alternative has the highest maintenance energy need. In the study material selection affect on embodied energy and operational energy can be seen clearly.

In another study from C.Thormak, building material replacement alternatives have compared in passive solar house (Thormak, 2006). Exisisting building components redesign with minimum material replacement but same thermal resistance conditions. Study has focused on embodied energy and recycling potential of components. Three alternatives of building components, which are exisisting component, minimum embodied energy alternatives and maximum alternative, have compared. According to study, embodied energy of minimum alternative is %17 lower than exisisting components and maximum redesign alternative embodied energy amount is %6 higher than exisisting alternative.

K. Ferit Çetintaş, compare different building envelope alternatives effect on embodied energy and carbon emission in related study (Çetintaş 2019). According to the results of the study, different thermal insulation materials with the same thermal conduction coefficient have a high effect on the embodied energy and carbon emission of the building envelope. The study revealed that the embodied energy savings achieved by using glass wool thermal insulation material instead of XPS is approximately equal to the annual heating energy consumption of the reference building (Çetintaş, 2019).

Smart materials' applications to building envlope has been researched by Francesco Sommese and others. The study remarked that the building envelope should be adative to the environment for reducing energy consumpiton. Therefore smart materials such as hydrogel, photocromic and thermoresponsive polymers have energy saving potential (Sommese et al., 2023). When the application of smart materials is suitable, their capacity to leverage environmental factors as passive triggers for adaptation, coupled with the relative reduction in energy consumption, qualifies the solution as a resilient approach (Sommese et al., 2023).

The last example which show the material selection's impact on the embodied energy and operational energy in Indonesia. Agya Utama and Shabbir H. Gheewala focused on 'embodied energy of building envelopes and its influence on cooling load in typical Indonesian middle class houses ' (Utama and Ghewala, 2006). In this study a typical single family house has compared with different material selection for building components according to embodied energy and operational energy for cooling loads. Alternatives are brick wall with a clay roof and concrete block wall with concrete roof. Alternative 1, which has concrete block, embodied energy amount is %30 higher than alternative 2 (brick wall and clay roof). In addition alternative 2 cooling load is %30 lower than alternative 1 (Utama and Ghewala, 2006). Results shows that material selection gives about %30 energy efficiency in embodied energy and operational energy in a conventional house unit in Indonesia. As it is stated in the examples material selection in building envelope has great impact embodied energy and operational energy consumption of building. In addition material selection has great impact on environment too.

2.3 Material selection impact on environment

Each building material has different origin so each material has different impact on environment. Environmental impacts of building material are an important as well as their embodied energy. Environmental impacts of buildings are related with their component's materials. Nowadays building material's environmental impacts is formed of building's sustainability. There are some studies on building's impact on the environment. Life cycle assessment method is used to evaluate building's impact on environment mostly.

Different construction types such as mass timber, reinforce concrete and structural steel has been compared according to environmental impact by Vabihav Kumar and others. The study remarked that structural material of the building has affect its environmental impact widely (Kumar et al., 2024). Building which has a mass timber structure reduce global warming potential in range of %39 to %51 (Kumar et al., 2024).

Canay Çamur was compared EPS and rock wool insulation materials with a life cycle assessment method in her master thesis (Çamur, 2010). GABI life cycle assessment software was used for evaluation in the study. As a result of the study EPS insulation material give better results than rock wool from view waste generation, environmental impacts and energy use. For instance SO2 emission of rock wool nearly as twice as EPS (Çamur, 2010) . Appu Haapio ad Pertti Viitaniemi have investigated that how does affect different structural solutions and materials building's impact on environment (Haapio and Viitainmei, 2008). Environmental impacts of 78 single family houses were calculated in the study. The buildings have different material layers and different length of service life varies from 60 years to 160 years. Environmental impact calculations were made with ATHENA impact estimator software. For instance, rock wool, cellulose and fiberglass insulation materials were compared according to some environmental impact indicators such as global warming potential, air pollution index, and water pollution index and energy consumption. According to calculation results, cellulose has lowest and rock wool has highest impact on environment. Each building component such as windows, envelope, roof and structure were evaluated according to their environmental impacts. As a result of the study from an environmental view best environmental options for building components were determined under identified conditions. The building components which have low resource consumption and low pollution to environment are identified as 'environmental friendly material' in the study. Moreover, wall insulation: cellulose (exterior), fiberglass (interior), cladding: wood tongue-and-siding, window frame: wood frame window, and roof material: steel or concrete tile options are found as environmental friendly material options for building components for this study.

Houda Ajabli, et all, focus on eco friendly thermal insulation materials' impact on indoor comfort. The study remarks that Eco-friendly insulation materials generate minimal waste during installation and can be recycled at the end of their lifecycle. In addition their impact on indoor comfort more extensvely. Therefore evironmental effects which is caused by XPS insulation material using could be reduced (Ajabli et al., 2023).

Liang et al., (2023) have studied on decarbonization potential of buildings from life cycle perspevtive (Liang et al., 2023). The study suggested that prefabrication in construction industry helps the decarbonization with using raw materials effective and recycling waste materials has various environmental benefits.

Kim., et all have studied on low carbon durability design for green apartment buildings in South Korea (Kim et al., 2017). Achieving high durability in apartment building structures can be accomplished by selecting materials with superior durability, thereby reducing CO2 emissions through a decrease in the quantity of materials used. This study focuses on concrete, as most apartment buildings in South Korea are constructed with reinforced concrete structures, making the service life of structural members reliant on concrete durability (Kim et al., 2017).

3. Findings

In this section, information obtained from studies in the literature has been compiled and building material selection criteria have been compiled to minimize environmental impacts from a life cycle perspective. Material selection criteria will be explained under separate headings by dividing the life cycle process into periods.

3.1 Material selection guidelines for reducing environmental impacts

Building material selection is a complex problem not only in construction industry but also in other industries. There are some guidelines and environmental friendly material selection methods to solve material selection problem in industries. But most of these guidelines are identified clearly; most of them just give fundamental items for the selection.

The Environmental Preference Method (EPM), which was developed by Woon and Energie in 1991, has been first attempt to developed a decision making tool for environmental friendly material selection (Anik et al., 1996). EPM method based on Life Cycle Assessment method from simple way. EPM is a very well known method which has used in many studies. David Anik and others used EPM method for building material selection (Anik et al., 1996). They studied on a hand book of sustainable building which was formed with EPM method. Building material suggestions for each building component are found in the study. Moreover, there is a list of materials, which should be avoided because of its environmental pollution, for each building component in the study. But these kinds of selection methods cannot be applied in all countries. Material production technology, production energy source, transportation type, distance and effects of geographic conditions on environmental pollution change country to country. For instance according to David Anik and others study timber window frame identified as 'preference material' from view of environmental performance (Anik et al., 1996). But in some Middle East countries timber provides from another country with long distance. Because of that timber frame cannot be best solution in these countries.

Each study on material selection focus subject in a same frame but from a different angle. This situation makes confusion for material selection. In this paper some studies on reducing environmental impacts with material selection researches and guidelines try to be summarized with a systematic approach (Anik et al., 1996; Sam, 2012; John and Brenda, 1998a; John and Brenda, 1998b; Bjorn, 2009).

3.2 Material selection guidelines for building vertical envelope for Turkey and its applicability

Major aim of the paper is to summarize material selection in building vertical envelope for Turkey and discussion applicability of guidelines to Turkey. Material selection is limited with building vertical envelope for this study but it can apply to all building components. It is an introductory study to develop guidelines for Turkey. Guidelines summarized with a systematic approach and they are based on phases which are parts of the material' life cycle. Guidelines divided into three phase which were pre use, use and post use phase.

Preuse phase guidelines: Preuse phase includes from raw material extraction to transportation to construction site. Guidelines summarized from studies (Anik et al., 1996; Sam, 2012; John and

Brenda, 1998a; John and Brenda, 1998b) in a table 1. But some of these guidelines and their application to countries such as Turkey/Istanbul should be discussed.

Raw material section: Material's origin and source have great impact on environment. Material has natural origin and from renewable sources should be preferred. But this item cannot be applied well for Istanbul. For instance in LEED green building certificate system, non using timber products from non renewable forests is an obligatory criteria and all timber products should have label about their source (LEED, 2023) . In Turkey there is no any labeling system about timber products origin. Constructer and architects doesn't know material exact source and origin in Turkey because lack of data. Another important point in raw material section is about its origin. Material has natural origin from polluted lands has harmful effect on indoor air quality. But it is difficult to find data about material's source and land's quality in Turkey.

Transportation: Transportation is another complex problem for evaluation. In most of studies material should preferred from 'short' distances but there is no any identification about short distance. For instance, a distance which is identified as short for United States can be very long distance for small countries such as Holland. Transportation type is another issue for this section. Type of transportation affects emissions to environment directly. Truck type is very important for emissions. In Europe Union trucks should provide carbon emission standards. In Turkey, regulatory standards have been established to limit carbon emissions produced by motor vehicles. Nonetheless, it has been documented that certain vehicles employed in road freight transportation fail to adhere to these regulations.

Production: Production technology is another important issue for environmental impacts. Each factory's energy and raw material consumption are different because of production technology and production effectiveness. Difference in effectiveness and production technology affects environmental performance of materials. Embodied energy of a building material related with its environmental performance. High embodied energy materials have great impact on environment. Calculation of embodied energy and raw material usage can be a complex problem for countries which has any database. In Turkey there is not any database about building materials embodied energy and environmental impacts. In Turkey LCA studies in construction sector use database from abroad. That is why all studies have discussed because of lack of data. A questionnaire has done to evaluate environmental performance of building materials by Uğur Kaya (Kaya, 2010). He stated that it is difficult to measure environmental impacts of building materials because of lack or inadequate data in Turkey. Productions of some building materials are done by different contractors and final mounting is done in another factory. Therefore, data about embodied energy and environmental impacts cannot be find or measure easily. In Turkey some factories use high technology energy, water recovery systems and filters for pollution reducing but most of the factories do not use these technologies. That is why emissions and energy consumption amounts can change hugely from factory to factory.

Use phase guidelines: Use phase guidelines include construction, use and maintenance phase. The guidlines can be seen in Table 2.

Construction: Construction phase is another complex part because of workmanship and use conditions have to be taken into account. Workmanship quality affects a material's performance directly. In some countries there are some standards for mounting of building components but in some countries such as Turkey there isn't any standard for workmanship in detail.

Use and maintenance: Use conditions have great impact on a material performance. Use conditions effects material's durability and maintenance need. Use conditions cannot be predicted so performance failure due to use conditions is unpredictable area of material selection. Service life of a building material has different value in each country. The difference in service life affects material maintenance or replacement needs which affect materials environmental impacts directly. Countries such as England has their own material's service life standards. In Turkey, service life of building materials standards are interpretation of international standards. Related standards have to be developed according to Turkey's conditions to get adequate results. Another issue in this phase about maintenance. In some countries such as England (BS 8210 or SFG20) and Sweden maintenance of materials are clearly defined with standards but in Turkey there is not related standards about maintenance of building materials or elements.

Post use phase guidelines: Post use phase guidelines include demolition phase. The guidlines can be seen in Table 3.

Demolition: Demolition is the last phase of a material in its life cycle. From an environmental approach material should be re use or re cycle after its life end. In LEED green building certificate system, some amount of the whole building material should be reusable and recyclable is a necessity (LEED, 2024). Recycling of some building materials is based on technology availability. For instance in Turkey some building materials cannot be recycled because of lack of technology. Moreover some manufacturers have any idea about reusing (Kaya, 2010). Therefore, serious amount of building materials which can be reuse or recycle, turn into waste without any processing. Demolition techniques, which affect environment

Table 1. Preuse phase guidelines for building vertical envelope material selection.

PHASE		CRITERIA	PREFERENCE	NOT RECOMENDED
PRE USE PHASE	RAW MATERIALS	Materials origin: Natural, Artficial, Recycled	Natural, Recycled	Artificial
		Materials source: Renewable, non renewable	Renewable	Non renewable
		Content: Harmful substance or not	Presence without harmful substances	Content harmful substances such as radon gas
		Availability	Available and wide spread sources	Lack of sources
		Energy consumption during extraction	Low energy need for ext and from renewable sources	High energy need for ext. And use of fossil fuels
		Environmental impacts during extraction soil, water, air, human, habitat etc.	Have low environmental impact mat. Such as timber, stone	Have high environmental impact mat. Such as aluminum, steel, zinc
	TRANSPORT	Transportation type: Truck, Railway, Air, Sea	Materials provide from local sources in short distance with effective transport type	Materials should not be provided from long distance companies
		Distance		
	PRODUCTION	Energy consumption during production	Low production energy need material (natural)	Highly energy need mat. For production such as steel, aluminum
		Production technology	Minimum level of production loss	In efficient production technology
		Water consumption during production	Minimum water consumption	High level of water consumption
		Environmental impact during production to air, water, soil, human and habitat	Minimum impact to environment during production	High level of impact to environment
		Waste generation during production	Minimum waste generation	Genrate huge amount of waste during production
	TRANSPORT	Transportation type: Truck, Railway, Air, Sea	Materials provide from local sources in short distance with effective transport type	Materials should not be provided from long distance companies
		Distance		

Table 2. Use phase guidelines for building vertical envelope material selection.

PHASE		CRITERIA	PREFERENCE	NOT RECOMENDED
USE PHASE	CONSTRUCTION	Energy consumption during production	Low energy need for production and from renewable sources	High energy need for prod. And use of fossil fuels
		Water consumption during production	Minimum water consumption	High level of water consumption
		Environmental impact during production to air,water,soil,human and habitat	Minimum impact to environment during production	High level of impact to environment
		Waste generation during production	Minimum waste generation	Cause huge amount of waste
	USE AND MAINTENANCE	Durability	High level of durability and materials have long service life	Low level of durability and materials have long service life
		Maintenance	Low maintenance need materials	High maintenance need maintenance
		Impacts on indoor environment	Low impact on indoor high quality	High impact on IAQ materials such as solvents, paints etc.
		Energy consumption during production and impact on env.	Low energy consumption and low environmental impact	High level of energy consumption and environmental impact

low, are not known by demolishing companies.

4. Results

Material selection is a process which affects building's performance and its sustainability. Reducing energy consumption and environmental impacts can be achieved through appropriate material selection. Although there are several material selection methods most of them does not include life cycle approach. Buildings and materials have different impacts on environment in life cycle stages. Therefore, life cycle performance of materials should be taken into account during material selection. Importance of considering the life cycle of building materials, including the embodied energy and carbon emissions associated with their production and disposal. But cosidering life cyle performance need comprihensive data about materials' and their origin. Lack of information and data is a critical problem in material selection. C. Thormak and U. Kaya highlighted same problem in their studies.

Table 3. Post use phase guidelines for building vertical envelope material selection.

PHASE		CRITERIA	PREFERENCE	NOT RECOMENDED
POST USE PHASE	DEMOLITION	Energy needs for demolition	Low energy needs for demolition and from renewable sources	high energy needs for demolition and use of fossil fuels
		Environmental impact during demolition to air, soil, water,human and habitat.	Minimum impact to environment during demolition	High level of impact to environment (explosives)
		Transportation type: Truck, Railway,Air,Sea	Materials dispose in short distance facilities.	Materials should not be disposed in facilities which is far way from site
		Distance		
		Re use ability	Materials which have a potential of re use	non re useable materials
		Re cycle ability	Materials that can be re cycled	non re cycle materials
		Disposal and degradation	Materials with the possibility of biological degradation	non-degradable material

It is stated before this is an introductory study for summarizing material selection guidelines and discussion of its applicability for Istanbul. A material selection method should take into account some parameters such as country's standards on building materials, laws, regulations, available information on material properties. Different material selection method should be developed according to building type, available data about material and expected environmental performance. The increasing number of criteria for material selection complicates the decision-making process. Considering both energy consumption and environmental impacts from a life cycle perspective further exacerbates this complexity. Therefore, it is recommended that future research focus on developing new material selection methods and tools employing optimization and decision-making techniques. It is anticipated that methods such as machine learning and deep learning will be utilized in future studies to predict environmental impacts, particularly in long and complex processes such as the life cycle of buildings, at the design stage. Considering material selection from a life cycle perspective requires comprehensive and high-quality data. However, there is limited data on the energy consumption and environmental impacts of building materials produced in Turkey during the production processes. Consequently, data produced abroad is often used for material selection processes in Turkey. Additionally, there are no standards or data available for a significant portion of the material selection criteria identified in this study. Therefore, many of the criteria determined within the scope of the study cannot be implemented in Turkey in the near future. Nonetheless, relevant institutions and organizations continue their efforts to address these data and standard deficiencies. It is recommended to develop methods that provide interim solutions until these improvements are made, or to use data from countries with similar conditions to Turkey for the material selection process.

Declaration of Ethical Standards

All ethical standards were followed in this study.

Credit Authorship Contribution Statement

Conceptualization, Methodology / Study design, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review and editing, Visualization has done by author.

Declaration of Competing Interest

The author has no conflicts of interest to declare regarding the content of this article.

Data Availability

All data generated or analyzed during this study are included in this published article.

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