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Sustainable Maintenance Strategy for Wood Windows Defects

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Abstract

Regular maintenance and repair of window systems in the existing building stock provide both resource and energy savings. While planning the maintenance strategy of window systems that offer benefit in terms of two different aspects, first of all, the possible damage types should be known. Then, what is the damage to the scope of this study? The question was investigated, and the causes and types of defects in the wooden windows were listed. The proposed maintenance planning method is based on 5 tools. The tools that can be used for maintenance planning are listed in the literature. First, the defect levels of the wood windows were specified and then the AHP method was used to select among the alternative maintenance according to the severity of the defect. The study was planned according to the 6 Sigma tool. Firstly, the causes of the defects were investigated and then these defects were evaluated by assigning numbers to each defect by experts. Finally, the AHP method was used to select the right alternative among proposed maintenance alternatives according to the level of defects. By using this simple method while choosing the window maintenance strategy according to the demands, wrong decision-making will be prevented.

Keywords: maintenance, wood window, defect

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1. INTRODUCTION

Defects in window systems can be diagnosed not only by complex tools, tests, etc. but also by observation-based inspections with simple-to-use hand tools. The accuracy of this method can be proved by different research tools. According to the results, the defects can be rehabilitated with maintenance actions that will increase the comfort of the user and meet the expectations, and the possible damages can be prevented or postponed. The questions asked in this study were as follows: Are the defects in the components of the window systems related to each other? What are the most common defects in wooden window systems? At what stages were they occur?

Windows are exposed to deterioration from the date they are built. However, the sustainability of building conditions is the main purpose of providing services to the users [1, 2]. Windows are openings on the building facade that have to meet multiple performance requirements. The window provides natural light and ventilation while protecting the inside from outside conditions. The window system is constantly exposed to both climatic influences and daily use that accelerates deterioration, leading to premature damage that affects the window's durability, appearance, and value. Therefore, it is necessary to classify damages to diagnose anomalies correctly and find the appropriate solution [3]. Appropriate maintenance should be performed to control irreversible defects in window systems and to extend the physical life of the building [2].

The method was applied to the historical education building. Defects have been detected in the windows of the building by observation-based and non-destructive inspection methods, and the detected damages have been matched with the maintenance recommendations corresponding to the defects in the previously created database.

2. DEFECTS AND MAINTENANCE METHODS IN WOOD WINDOW SYSTEMS

In the building sector, there are words with different meanings that are thought to have the same meaning concerning building defects. It is necessary to know the equivalents of these words in defining the problem well. The words which are thought to have the same meaning in the literature but they are different as follows:

- “Error” wrong human action - wrong choice or decision,
- “Fault”, an element fails to perform the intended action,
- “Defect”, in which one or more elements are not performing”,
- “Snag ”, obstacle,
- “Anomaly”, Probable defect that is anomaly-directly visible or measurable,
- “Degradation”, something is destroyed
- “Damage”-It is defined by the words deterioration expressed in terms of cost.

Atkinson (1987) has made a very clear definition of differentiating defects from failure. Failure means formations that may or may not be corrected before the building is delivered, on the other hand, the defect is the decrease in performance after the building is started to be used [27,4]. While error and failure terms are very close to each other due to their meaning, the error is usually related to human movements while defect occurs in elements [4]. According to Flores and Brito (2010), maintenance rehabilitations are actions taken during operation of a building to secure minimum performance levels without any deterioration of the elements of the building and to maintain the commercial value of the building and ensure sustainability [5, 6, 9].

2.1. Defects in Wooden Systems

Degradation of wood materials occurs in the form of mold, blight, cavity formation, breakage, cracking and so on since microorganisms and pests live within these materials. Components made with wooden material that is susceptible to such degradation due to the damp internal structure may deteriorate very quickly and become irreparable if necessary, precautions are not taken according to the places where they are used. It is possible to extend the service life by regular maintenance of the window systems made of wood materials that are directly exposed to external climatic conditions.

Defects occur in windows due to the following reasons [11],

- Incorrect design
- Incorrect construction
- Improper maintenance
- Faulty material
- Improper use
- Lack of information
- Poor communication

The reasons for the transition of windows from performing to the non-performing condition must be identified. Degradation may not be attributed to only one reason. Natural degradation begins with the aging of materials and components/elements. On the other hand, failures depend on design or construction. The degradation process takes time to evolve, and the performance of the components does not immediately pass from to another. This is crucial for the planning of preventive maintenance strategies. Degradations often occur before the final damage/defect occurs [28]. The type or severity of the defect affects the performance of the construction components. Most condition assessment methods classify the defect type of different building components as unimportant, important and critical. Critical defects significantly affect the function of the structural component. Serious defects show symptoms by causing deterioration in performance. The intensity of defects has a strong impact on the condition of the building components. Straub (2014), 'prepared a table that lists the defects threaten the function in the windows by referring to Damen et al. [12], [10]. (Table 1-2)

Table 1. Classification of defects in windows (Developed from [10])

Critical defects	Serious defects	Minor defects
Distortion and leakage, Frame breakage and cracking, Mushroom formation Cracking Insect Attack Track loss Strain Rupture	Aging of sealing materials Wear of gaskets Loss of protective layer Having mist on double glazing units Moisture retention of window frames Partial spaces Water leakage Corrosion on fasteners Degradation in fasteners	Deterioration of surface finishes Discoloration-fading Color change on glass surface Pollution

2.2. Methods Used in Diagnosis of Defects

Please be sure to check your document for spelling and grammar before submitting it electronically. Observation-based, simple instruments and more complex instruments are used to diagnose degradation in window systems. According to Masters (1985), what should be known in the estimation of service life are as follows [13, 14].

- A systematic approach to treating/solving the problem,
- In-service performance of the material,
- Knowledge about environmental factors causing degradation,
- Knowledge of mathematical models that define material behaviors with specific applications and environment,
- Number of factors causing degradation,
- Geographical location and the importance of factors changing with the available material,

Knowledge of the range of factors needed for the development of test methods to estimate the service life.

Table 2. Classification of defects in wooden frames (Developed from [3])

DEFECTS GROUP	DEFECTS NAME
A-DEFECTS IN DESIGN	A1-Wrong window type selection A2-Failure to place the casing in the right place (inside, center, outside) A3-Unprotected window (eaves etc.) A4-Faulty design of sills A5-Lack of water drainage system / failure A6-Overlap number is not selected correctly A7-Incorrect section selection A8-Missing connection due to through-opening A9-Inadequate selection of fittings A10-Not selecting the appropriate glass type / thickness A11-Designing / detailing the wrong water discharge system A12-Designing / detailing the wrong window sill A13-Insufficient number of fasteners during design A14-No incorrect design / ventilation elements A15-Failure support design A16- Incorrect selection of frame section and sash A17- Incorrect selection of frame profiles A18-Excessive frame angle (deflection problem) A19-Failure sealing material selection ………………………..
B-DEFECTS IN CONSTRUCTION	B1.Faulty fixing of the case to the wall B2-Improper insulation of the casing and wall B3-Incorrect detection of the sash to the frame B4-Incorrect detection of sealing elements B5-Incorrect fixation of glass strip B6-Incorrect application of water drainage system B7-Poor workmanship B8-Use of inexperienced or inadequately qualified workforce B9-Use of inadequate, poor quality and / or non-approved materials B10-Fixation with missing fasteners ……………………
C-DEFECTS IN USE	C1-Number of users C2-Poor maintenance C3-Incorrect using of mobile parts C4-Improper use of the closing mechanism C5-Lack of maintenance …………………..

2.3. Methods Used in Diagnosis of Defects

Please be sure to check your document for spelling and grammar before submitting it electronically. Observation-based, simple instruments and more complex instruments are used to diagnose degradation in window systems. According to Masters (1985), what should be known in the estimation of service life are as follows [13, 14].

- A systematic approach to treating/solving the problem,
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- Number of factors causing degradation,
- Geographical location and the importance of factors changing with the available material,
- Knowledge of the range of factors needed for the development of test methods to estimate the service life.

Visual inspection of degradation of the windows (Table 3) can be carried out with simple on-site measurements (thermographic instruments). The complex process of deterioration in windows occurs due to several factors. Understanding the pathological methods and knowing these factors are important for controlling the appropriate maintenance method [15]. In this study, defects in wood window systems were determined based on observation.

Table 3. Diagnostic Method

Table 3. Diagnostic Method	
Based on Observation	Crack and gap sizes Angle measurement Alignment

2.4. Maintenance Methods

When the necessary precautions are taken against the defects that occurred or may occur in the window systems, the expected performance level of the window can be kept at the desired level. To achieve this, it is necessary to plan the process well and to plan maintenance with a systematic approach. The consequences of an inefficient maintenance policy go far beyond the cost of maintenance [5, 8]. In the literature, maintenance methods are widely examined in three stages.

1. *Predictive maintenance;* this type of maintenance is suitable for elements whose performance and condition can be observable. Inspections are planned and the maintenance actions are performed according to the inspection results under the degradation conditions of the element. Predictive strategies are based on a large number of technical and statistical knowledge of the building element's behavior [7].

2. *Preventive maintenance;* is performed at predetermined intervals to prevent defects. Preventive maintenance planning requires extensive knowledge of service time, service performance, deterioration models, effective maintenance operations and costs for each staff member [15].

3. *Corrective maintenance;* In cases where the effect of the fault is very small, corrective maintenance is applied. According to corrective maintenance, inconvenience caused by unplanned errors can be solved with very small costs [15].

4. *Time-based maintenance:* after the 2000s, there has been a transition to state-based maintenance [7].

3. METHODOLOGY OF THE STUDY

The research aims to determine the causes of defects in the wooden window systems of the existing structures and to select the most appropriate maintenance alternative for these defects according to the demands of the user. For this purpose, extensive literature review and standards and regulations were examined. The possible defect types and diagnostic methods that can be encountered by these investigations have been determined, and then maintenance alternatives have been listed. In the methodology of the study, the problem will be solved by using 4 steps with 5 tools (Table 4,5; Figure 1). In this study, to have multiple criteria affecting the deterioration of the window system, Multi-Criteria Decision-Making Methods (MCDMM) were investigated. The study was structured based on the 4 Stages of the 6 Sigma (Table 4) research method. The method consists of identification, measurement, analysis, improvement, and control. The control phase could not be performed in the study. Because the proposed maintenance and repair proposal has not been implemented but remained as a proposal.

Data is collected and recorded in the control list based on the observation of the expert diagnosing the defects in the windows.

The expert must have all the necessary information, such as the location of the building, the year of construction, the functional characteristics, the previous maintenance of the window. All this information should be stored in a standard database [15]. The following steps were followed according to 6 Sigma Research Method.

3.1. Description

In this stage defects in window systems are explained. Root causes of defects are tried to be determined by using cause-effect analysis in determining the defects in the windows. The path to be followed is determined by the workflow chart (Figure 1).

3.2. Measurement

The expert records the current status of the structure and the window as well as the historical information in the template specified in Table 6. The status of the window is determined by this table which we will call as a checklist. The aesthetic and physical damage levels of the window systems divided into 5 sections in the checklists are graded between 1-5. In this way, the damage that can be corrected, monitored and/or done can be determined. The process continues by following the workflow chart. In the second stage, the damage is scored for prioritization. In the third stage, the procedure is completed by selecting the appropriate maintenance from the archive of the previously created maintenance proposals by the AHP method.

3.3. Analysis Stage

The reason for the same defect types in the window systems is investigated. The matrix in Tables 7 and 8 and the checklist in Table 6 will be filled according to where the aesthetic and physical defects occur, the reasons for their occurrence and the stages. Knowing the causes of damages is important in terms of protecting the window, not making the same failure again and making maintenance planning by taking these reasons into consideration.

3.4. Improvement Stage

The maintenance plan is applied according to the score obtained for the selected window. After inspection, the criteria for maintenance prioritization are analyzed, and the most appropriate criteria are identified based on the relative weight. Depending on the type of physical performance or construction solution, it is possible to determine an index that reflects the priority of intervention, urgent actions (up to six months), short-term (up to two years) and medium-term actions by combining certain factors related to risk (critical type of the affected area and maintenance cost). Heat, sound and water problems occur due to the defects in window systems. In order to eliminate these problems, alternative maintenance plans are developed according to the data obtained from the window types which are examined, and the most suitable one is selected and applied (Table 9).

3.5. Control Stage

At this stage, the recommended maintenance planning for window systems could not be carried out. Therefore, this stage is not applicable within the scope of our research (we could not have a sponsor for this purpose).

Table 4. Sigma Improvement Tools- Management and Quality Tools

Table 4: Sigma Improvement Tools- Management and Quality Tools				
Method		**Purpose of Usage**	**Benefits**	**Source**
Customer's Requests		The objectives of the project are set out and the customer's wishes are fully understood so that the problems that arise after are eliminated.	The contract with employees for the realization of the objectives of the project reduces the likelihood of problems because the obligations are determined.	
Brainstorming		Idea development	It is a process in which different ideas are freely expressed by everyone. Ideas are ranked from 1 to 5 according to their	Munro, 2007 [16]
Gantt chart		Making the job program	Completing the project steps in the desired time and order to prevent possible disruptions	Pande et. al, 2001 [17]
Work Flow Charts and Process Mapping		Observing, identifying and improving problems are important in deciding the processes	Observing, identifying and improving problems are important in deciding the processes	
Prioritization Matrix		Choosing between options	Choosing between options	Munro, 2007 [16]
Hypothesis Testing and ANOVA		Propose to special situations	Used to propose solutions to special situations with statistical data	
Regression Analysis		Used to explain how the dependent variable is changed by the argument		
Benchmarking		It is used to apply a system process to another system.	Organizations benefit from each other's positive aspects	
Control Chart		Used to distinguish process variations	Used to control the process.	Sönmez, 2013 [19]
Process adequacy index		Process adequacy is the ability of the process to meet the expected specifications.		
Faiulere Types and Effects Analaysis-HTEA FMEA-Fault	**FMEA**	It is used to track all failures in the process step by step.	The frequency of failures is listed according to their causes and severity.	Pahl et.al, 1996 [23]; Tooley and Knovel, 2010 [24]
	Root cause analysis	It is a step-by-step method used to analyze problems based on root causes.	It is a step-by-step method used to analyze problems based on root causes.	Ben-Daya et. Al, 2009 [18]
	Pareto Diyagram	Used to see the frequency of failure types.		
	Cause and Effect Diagram Fishbone Method	This tool helps to identify the underlying causes of the problem in Six Sigma.	It is easy to use and generally gives remarkable results.	Munro, 2007 [16]
	Fault Tree Analysis	Top-down sequence of possible failure events after a significant failure.		Pahl et.al, 1996 [23]; Tomiyama et al,2009 [25] Shetty, 2016 [26]
	Fuzzy Logic and Fuzzy Clustering Method - FDM	The fuzzy set can be defined mathematically as assigning a value to any entity in the discourse universe to the degree of membership within the fuzzy set.	Fuzzy logic is an appropriate methodology to investigate many problems characterized by unreliable data, incomplete measurements, and ambiguous definitions.	Zadeh, 1975 [20]
Control Sheets		Data collecting	Provides more organized data collection process.	

Table 5. Methodology of the study; tools and steps that used in this study

Tools	Steps	Method
Cause and Effect Analysis	Identification of defects	-
Brainstorming Checklist **(Figure 1)** Workflow chart	Identifying defects in components	Based on observation method
Scoring	Scoring of defects	-
AHP	Selecting appropriate maintenance Response severity / urgency level	-

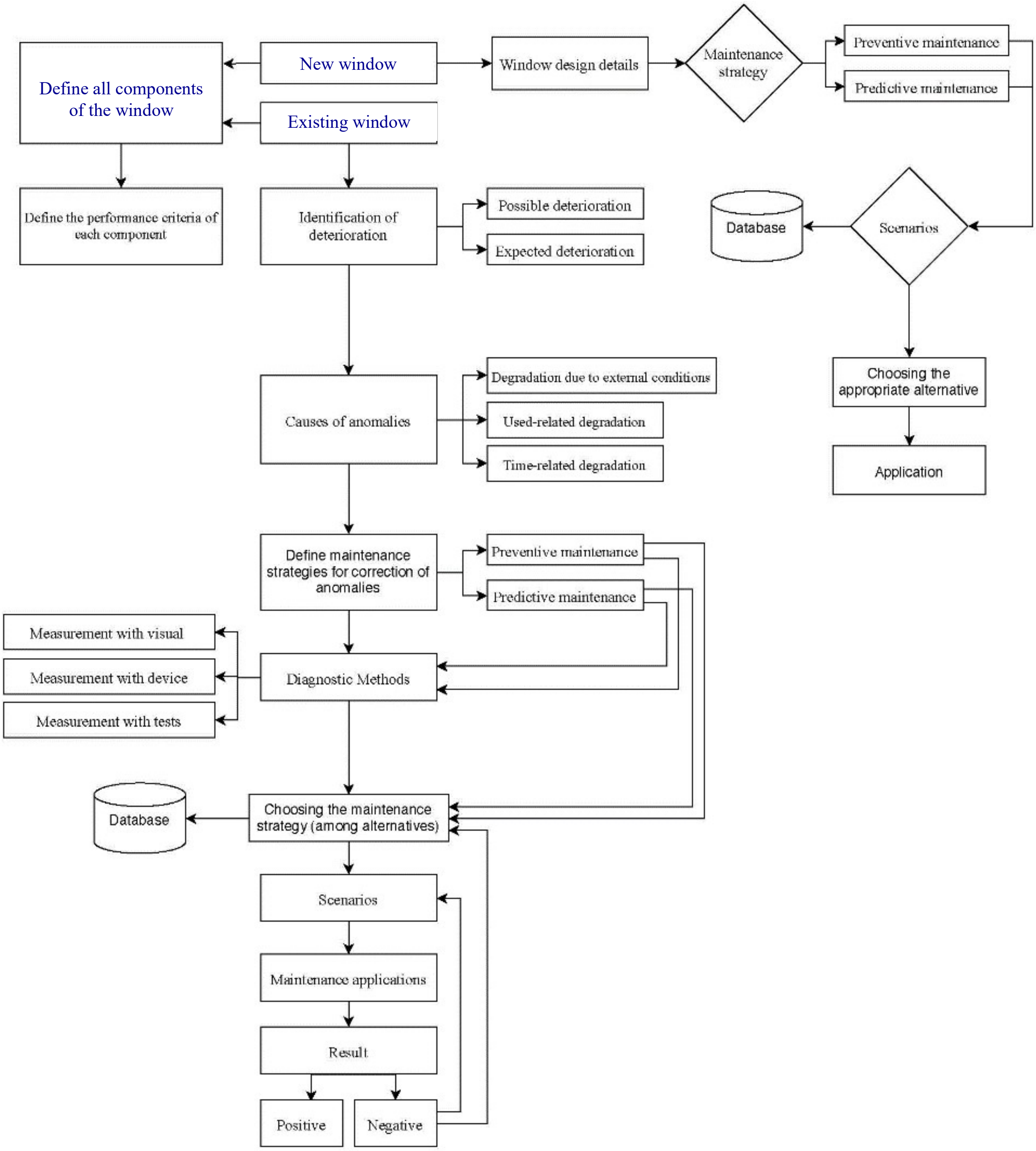


Figure 1 Workflow Chart for Window Maintenance Planning

Table 6. Checklist

Table 6: Checklist		
Code:	**Name of the Building:**	Photos of window
General Information about Building	**Function of Structure:**	
	Function of Space:	
	Supporting System of the Building:	
	Floor location:	
	Distance to Sea:	
	Distance to Road:	
	Direction:	
General Information about the Window	**Wall Type:**	
	Position of the window on the wall:	
	Protective element on the wall: (wiping, eaves, etc.)	
	Lintel:	
	Sills:	
	Window Size:	
	Material of the window:	
	Glass Type:	

DEFECTS IN WINDOW SYSTEM COMPONENTS		**DEFECTS TYPE**	**Score**		**DEFECTS TYPE**	**Score**
SASH -GLASS	**Aesthetic Defects**	E1. Rupture		**Physical Damages**	F1. Distortion-Breaking of Fasteners	
		E2. Smooth Pollution			F2. Corrosion in Fasteners	
		E3. Color Change			F3. Water Leakage	
		E4. Mold fungus			F4. Partial Blanks	
		E5. Cracking			F5. Sealing Deterioration	
		E6. Swelling			F6. Shattered Glass	
		……..			F7. Heat problem	
	Failures in Design		**Installation Failure**		**Failures in Use**	
FRAME-SASH	**Aesthetic Defects**	E1. Rupture		**Physical Damages**	F1. Distortion-Breaking of Fasteners	
		E2. Smooth Pollution			F2. Corrosion in Fasteners	
		E3. Color Change			F3. Water Leakage	
		E4. Mold fungus			F4. Partial Blanks	
		E5. Cracking			F5. Sealing Deterioration	
		E6. Swelling			F6. Shattered Glass	
		……….			F7. Heat problem	
	Failures in Design		**Installation Fail.**		**Failures in Use**	
SASH*SASH	**Aesthetic Defects**	E1. Rupture		**Physical Damages**	F1. Distortion-Breaking of Fasteners	
		E2. Smooth Pollution			F2. Corrosion in Fasteners	
		E3. Color Change			F3. Water Leakage	
		E4. Mold fungus			F4. Partial Blanks	
		E5. Cracking			F5. Sealing Deterioration	
		E6. Swelling			F6. Shattered Glass	
					F7. Heat problem	
	Failures in Design		**Installation Fail.**		**Failures in Use**	
WALL-FRAME	**Estetik Hasarlar**	E1. Rupture		**Physical Damages**	F1. Distortion-Breaking of Fasteners	
		E2. Smooth Pollution			F2. Corrosion in Fasteners	
		E3. Color Change			F3. Water Leakage	
		E4. Mold fungus			F4. Partial Blanks	
		E5. Cracking			F5. Sealing Deterioration	
		E6. Swelling			F6. Shattered Glass	
		……..			F7. Heat problem	
	Failures in Design		**Installation Fail.**		**Failures in Use**	
LINTEL-FRAME	**Aesthetic Defects**	E1. Rupture		**Physical Damages**	F1. Distortion-Breaking of Fasteners	
		E2. Smooth Pollution			F2. Corrosion in Fasteners	
		E3. Color Change			F3. Water Leakage	
		E4. Mold fungus			F4. Partial Blanks	
		E5. Cracking			F5. Sealing Deterioration	
		E6. Swelling			F6. Shattered Glass	
		……			F7. Heat problem	
	Failures in Design		**Installation Fail.**		**Failures in Use**	
SILLS-FRAME	**Aesthetic Defects**	E1. Rupture		**Physical Damages**	F1. Distortion-Breaking of Fasteners	
		E2. Smooth Pollution			F2. Corrosion in Fasteners	
		E3. Color Change			F3. Water Leakage	
		E4. Mold fungus			F4. Partial Blanks	
		E5. Cracking			F5. Sealing Deterioration	
		E6. Swelling			F6. Shattered Glass	
		……			F7. Heat problem	
	Failures in Design		**Installation Failure**		**Failures in Use**	

Scoring System: 1: Excellent (no damage) 2: Good (damage that can be easily corrected) 3: Moderate (usable - maintenance required) 4: Bad (parts replacement required) 5: Very bad (parts cannot be replaced, cannot be used See Table: List of design, construction, usage failure

Table 7. Matrix related to defects and possible causes of windows

Defects Code		Region of Origin			Possible Reasons						Stages			
		Y1	Y2	Y3	N1	N2	N3	N4	N5	N6	T	Y	K	Ç
Aesthetic Defects	E1													
	E2													
	E3													
	E4													
	E5													
	E6													
	E7													
	Total													
Physical Defects	F1													
	F2													
	F3													
	F4													
	F5													
	F6													
	Total													
Total														

* Y1: Sash-frame, Y2: Sash-sash, Y3: Sash-glass, Y4: Between wall-frame, Y5: Between Lintel-frame, Y6: Between sill-frame;
* Phases: T (design; Y (construction); K / B (use / maintenance); O (environment)
* Causes; N1- Small sash-frame section, N2-Incorrect installation, N3-

Table 8. Matrix of possible causes of defects in windows

Defects Code		Region of Origin			Possible Reasons						Stages			
		Y1	Y2	Y3	N1	N2	N3	N4	N5	N6	T	Y	K	Ç
Aesthetic Defects	E1													
	E2													
	E3													
	E4													
	E5													
	E6													
	E7													
	Total													
Physical Defects	F1													
	F2													
	F3													
	F4													
	F5													
	F6													
	Total													
Total														

Invalid use, N4-Incorrect maintenance-repair, N5-Incorrect positioning, N6-Incorrect selection
* Defects; The E and F codes are the codes of the detects given in the checklist in Table 11.

Table 9. Maintenance (Developed from [3])

Defect Locations	Maintenance Recommendations
HY1.Frame Components Maintenance	A1- Repair or replacement of EPDM, silicone, strip, etc. sealing materials A2- Repair / replacement of fasteners such as nail screws A3- Replacing the glazing bead A4- Repair / replacement of hinges, opening / closing mechanisms …………
HY2. Frame Maintenance	B1- General cleaning of the frame B2- Repairing damaged areas according to the material of the frame B3- Repair of drains and drainage B4- Removal of damaged parts of glass ……………..
HY3.Glass Maintenance	C1-Glass replacement C2-Glass repair C3-Installation of ventilation system …..
HY4. Frame-Lintel Maintenance	L1- Silicone squeezing between frame-lintel L2- Insulation if thinner than lintel wall L3- Strengthening frame fixings L4- Placing raincoats / profiles to remove rainwater etc. ……….
HY5.Frame-Sills Maintenance	D1-Silicone squeezing between case-windowsill D2- Installation of profile / raincoat to reduce water leakage between frame (case) and windowsill ……….

Table 10. Recommended maintenance for scoring from Table 9

	1 Point	2 Point	3 Point	4 Point	5 Point
Recommended maintenance	HY2-B1.	HY2-B1, HY1, HY2, HY4, HY5	HY2-B1, HY1, HY2, HY4, HY5	HY2-B1, HY1, HY2, HY3,HY4, HY5	HY2-B6

According to the score obtained as a result of the visual evaluations, the selection is made by applying the AHP method while planning maintenance for the relevant window. The AHP method is used in the selection of maintenance alternatives. The AHP method is one of the most widely used multi-criteria decision-making methods where the decision (selection and prioritization of alternatives) is based on a variety of tangible and intangible criteria (sub-criteria). The complex problem-solving process is divided into a hierarchical structure consisting of the purpose of the problem, criteria, sub-criteria, and alternatives. When designing the AHP hierarchical tree, the objective is to develop a general framework that meets the needs of analysts to solve the problem of selecting the best maintenance policy. AHP begins by dividing the complex multi-criteria problem into a hierarchy where each level contains several manageable elements that can be divided into another group of elements [22]. The AHP hierarchy developed in this study is based on the selection of the performance characteristics in the window system and the appropriate maintenance alternatives. Tables 9, 10 and 11 are used for selection of the best alternative.

4. APPLICATION of METHODOLOGY

4.1. Description Phase

The model is applied to a historical educational building which is near the sea. The examined defects are classified under the title of aesthetic and physical defects. The reasons for the defects were small frame-sash section, incorrect installation, incorrect use, incorrect maintenance, incorrect positioning, and incorrect selection, and it was decided to investigate whether all these faults occurred during the design, application or usage stages or environmental condition. At this stage, a workflow chart (Figure 1) was made to decide which stages to follow.

Table 11. Criteria to be used in the evaluation

Evaluation Criteria-Main Criteria and Sub-Criteria	
Structural performance	Structural stability
Durability	Security
Physical performance Ecological performance	Health
	Air impermeability
	Water impermeability
	Heat performance
	Sound impermeability
	Noise control
Cost	Natural ventilation
	Solar Control
	Use of recyclable materials
Structural performance	
Durability	Selection of materials and details suitable to the historical building
	Material in suitable color-texture

4.2. Measurement Phase

62 wooden window systems of the building were examined according to the checklist in Table 11. One of the long façades of the building is close to the sea and the other façade is parallel to the main street. The defects in the windows were investigated by observation, the data obtained from the investigation were recorded in the checklist and the defects were documented and archived with photographs (Tables 12- 13).

After completing the checklists, the data was converted to numerical values using Tables 14 and 15. It was found that 100% of the aesthetic damages occurred in the frame and sash and 15% in the glass.

Table 12. Defects in the windows

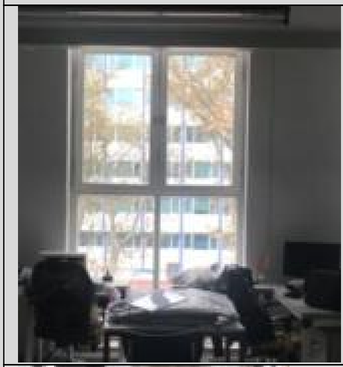
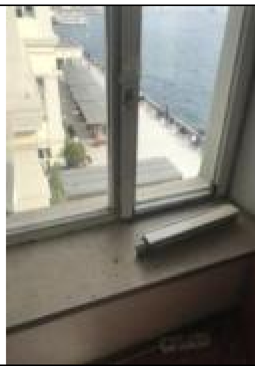
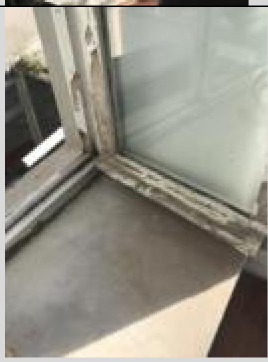
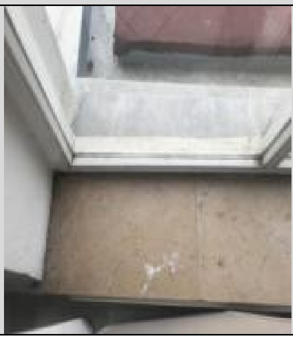
Defects in Window	Defects in Glass Bead	Defects in Sash	Defects in Frame
P2 Code window  Defect type: Glass contamination	**P56 Code window**  Defect type: Deformation of lath	**P3 Code window**  Defect type: Spill in paints	**P7 Code window**  Defect type: Clogging of water discharge pipes
P61 Code window  Defect type: Glass misting	**P60 Code window**  Defect type: Decay, crack formation, spill	**P53 Code window**  Defect type: Breaking, cracking, surface contamination	**P5 Code window**  Defect type: Decay, spill, spill between sill-frame

4.3. Analysis Phase

The wooden windows investigated in this stage were separated as wall-frame, window components, glass component, and places where defects occurred were examined in terms of aesthetic and physical defects. The reasons for the defects were evaluated under the headings of the small case-sash section, incorrect installation, incorrect usage, incorrect maintenance, incorrect positioning, and incorrect selection. Finally, it was investigated whether the defects occurred due to design, construction, usage and/or environmental conditions. The data are recorded in Table 14-15. According to Table 14, most of the defects are seen in the frame. It is determined that the cause of these defects is due to improper maintenance.

According to the data in Tables 14 and 15, defects in the window system investigated were assigned as follows. Aesthetic damages were seen in the frame and sash as smooth contamination, color change, mold fungus formation, cracking and blistering. On the other hand, only fouling was detected on the glass. It has been determined that these defects occurred due to incorrect maintenance and incorrect positioning. Decisions given according to the design and environmental factors were found to be important in the formation of these defects. It was further detected that partial cavities in the sash and the frame, decay, mold, and fungus were available, and the strip in the sash was completely removed, wherein heat problems occurred.

Table 13. Photographs for information on the status of windows according to defects

	2nd Degree Damaged Windows (P37 Code Window)	**3rd Degree Damaged Windows (P5 Code Window)**	**4th Degree Damaged Windows (Window P13 Code)**	**5th Degree Damaged Windows (Window P26 Code)**
There is no 1st degree damaged window				
				
				

There was also heat loss on the glass surface. It was also found that there was a gap, mold, and wear of the silicones between the frame-wall, the frame-lintel, and the frame-windowsill. 90% of these damages occurred due to design and environmental conditions. In the design, placing the window frames on the outer surface of the wall caused them to remain unprotected and hence, be exposed to severe environmental conditions directly.

4.4. Improvement Stage

All components are subject to loss of performance due to aging, handling and external reasons. Hermans 1995 [13] showed that the relationship between deterioration and performance loss could develop in three different ways (Figure 1).

1. While performance loss decreases continuously, distortion increases continuously.
2. No deterioration occurs when the performance is constantly at the same level, the performance suddenly disappears/diminishes.
3. Performance loss and defects are independent.

Tables 14 and 15 indicate scores assigned to the levels of defect, which were identified as an outcome of on-site observations. Table 14 shows in which stage or stages including design, application, construction and usage phases the deterioration of window components (frame, sash, glass, and their junction points) occurs by summing up the scores. Table 15 shows the deterioration score between the wall and the windowsill and whether it occurs due to the

Table 14. Matrix of possible causes of defects in the window system

Defects Code		Region of Origin			Possible Reasons						Stages			
		Y1	Y2	Y3	N1	N2	N3	N4	N5	N6	T	Y	K	Ç
Aesthetic Defects	E1	X	X					X		X			X	X
	E2	X	X	X							X		X	X
	E3	X	X								X		X	X
	E4	X	X											X
	E5	X	X											X
	E6	X	X											X
	Total	6	6	1				1		1	2		3	6
Physical Defects	F1													
	F2					X		X						X
	F3	X	X								X			X
	F4	X	X					X						X
	F5		X					X						
	F6	X	X					X						X
	F7	X	X	X				X			X	X		X
	Total	4	5	1		1		5			2	1		5
Total		10	11	2		1		6		1	4	1	3	11

Table 15. Matrix of possible causes of defects between wall and window

Defects Code		Region of Origin			Possible Reasons						Stages			
		Y1	Y2	Y3	N1	N2	N3	N4	N5	N6	T	Y	K	Ç
Aesthetic Defects	E1							X	X		X			X
	E2	X	X	X				X			X			X
	E3	X	X	X				X			X			X
	E4	X	X	X				X	X		X			X
	E5	X	X	X				X	X		X			X
	E6	X	X	X					X					X
	Total	5	5	5				5	4		5			6
Physical Defects	F1												X	
	F2								X					X
	F3								X		X			
	F4			X					X		X			
	F5										X			
	F6			X			X		X		X			X
	F7	X	X	X					X	X	X			X
	Total	1	1	3			1		5	1	5		1	3
Total		6	6	8			1	5	9	1	10		1	9

* Y1: in the casing-frame, Y2: in the sash, Y3: in the glass; Y4: Between wall-frame, Y5: Between Lintel-frame, Y6: Between sill-frame;
* Phases: T (design; Y (construction); K / B (use / maintenance); O (environment)
* Causes; N1- Small frame-sash section, N2-Incorrect installation, N3. Failure use, N4-Incorrect maintenance-repair, N5-Incorrect positioning, N6-Incorrect selection
* Defects; The E and F codes are the codes of the defects given in the checklist in Table 11.

With the previous scoring system, maintenance alternatives were selected for the windows design, construction and usage stages. The information obtained here is used in the selection of the maintenance method. having scores of 2.3 and 4. A selection is to be made among the options to upgrade the score of window systems from 2 to 1 point or to protect their current status and to improve the condition of window systems scored 3 and 4. Maintenance plans are created and selected for each grade.

In the study, the most appropriate maintenance and repair planning were made for the window system with the damage degree code of P13 among the 62 window systems examined. The most important damage detected in this window system is the presence of decay in the casing and cracks in the sash. The criteria were determined according to the rate of deterioration of the window. Maintenance planning has been subjected to general preliminary assessment in terms of heat impermeability, water impermeability, durability aesthetics, and cost criteria. In terms of heat impermeability, it was observed that there were leaks from these points where the strip on the edges of the window sash were worn. Heat transitions have been detected on the areas where the frame and sash connect, which caused swelling of the plaster and paint between the wall and the frame. When the water impermeability was examined, it was observed that the gutters made to prevent the ingress of water into the frame were blocked, and the frame was found to be rotting from the cracks caused by both water and sun rays. In terms of aesthetics, there is intense visual deterioration especially on the exterior surface with the rotting of the frame and sash. Decay was seen as critical damage in the examined window systems, and it was found that the sub-head of the sash was broken, and the sash could not perform its function. The second critical defect that occurred due to decay was spillage and cracking of the wooden frame, sash and glass laths. The common defect observed in almost all windows was the application of very thick paint on the surface, and swelling, as well as spilling of this thick paint layer depending on the environmental conditions, which means that the wood remained unprotected.

Table 16. Control List

Kod: P13	**Name of Building:** Historical Education Building
General Information about Building	**Function:** Education
	Function of room: Office
	Supporting System: Concrete+Masonary
	Floor Level First floor
	Distance to Sea: 4m
	Distance to Road: -
	Direction: North-east
General Information about the Window	**Wall Type:** Stone
	Position of the window on the wall: Outside
	Protective element on the wall: (wiping, eaves, etc.) Wiping, eaves
	Lintel: Arch
	Sills: no exist
	Window Size:
	Material of the window: Wood
	Glass Type: Two layered glass

DEFECTS IN WINDOW SYSTEM COMPONENTS

Component		Defect Location and Type	Yes-no		Defect Location and Type	Yes/No
SASH-GLASS	**Aesthetic Defects**	E1. Rupture	-	**Physical Defects**	F1. Distortion-Breaking of Fasteners	-
		E2. Smooth Pollution	X		F2. Corrosion in Fasteners	X
		E3. Color Change	X		F3. Water Leakage	-
		E4. Mold fungus	X		F4. Partial Blanks	X
		E5. Cracking	X		F5. Sealing Deterioration	X
		E6. Swelling	**X**		F6. Shattered Glass	-
		……..			F7. Heat problem	X
	Failures in Design	**X**	**Installatıon Failure**		**Using Failure**	**X**
FRAME-SASH	**Aesthetic Defects**	E1. Rupture	X	**Physical Defects**	F1. Distortion-Breaking of Fasteners	-
		E2. Smooth Pollution	X		F2. Corrosion in Fasteners	-
		E3. Color Change	X		F3. Water Leakage	-
		E4. Mold fungus	X		F4. Partial Blanks	-
		E5. Cracking	X		F5. Sealing Deterioration	X
		E6. Swelling	X		F6. Shattered Glass	X
		……….			F7. Heat problem	X
	Failures in Design	X	**Installatıon Failure**		**Using Failure**	X
SASH-SASH	**Aesthetic Defects**	E1. Rupture	-	**Physical Defects**	F1. Distortion-Breaking of Fasteners	-
		E2. Smooth Pollution	X		F2. Corrosion in Fasteners	-
		E3. Color Change	X		F3. Water Leakage	-
		E4. Mold fungus	X		F4. Partial Blanks	-
		E5. Cracking	X		F5. Sealing Deterioration	X
		E6. Swelling	X		F6. Shattered Glass	X
					F7. Heat problem	X
	Failures in Design	**X**	**Installatıon Failure**		**Using Failure**	X
WALL-FRAME	**Aesthetic Defects**	E1. Rupture	-	**Physical Defects**	F1. Distortion-Breaking of Fasteners	-
		E2. Smooth Pollution	X		F2. Corrosion in Fasteners	X
		E3. Color Change	X		F3. Water Leakage	-
		E4. Mold fungus	X		F4. Partial Blanks	X
		E5. Cracking	X		F5. Sealing Deterioration	X
		E6. Swelling	**X**		F6. Shattered Glass	X
		……..			F7. Heat problem	X
	Failures in Design	**X**	**Installatıon Failure**		**Using Failure**	X
LINTEL-FRAME	**Aesthetic Defects**	E1. Rupture	-	**Physical Defects**	F1. Distortion-Breaking of Fasteners	-
		E2. Smooth Pollution	X		F2. Corrosion in Fasteners	-
		E3. Color Change	X		F3. Water Leakage	-
		E4. Mold fungus	X		F4. Partial Blanks	-
		E5. Cracking	X		F5. Sealing Deterioration	X
		E6. Swelling	X		F6. Shattered Glass	-
		……			F7. Heat problem	X
	Failures in Design	X	**Installatıon Failure**		**Using Failure**	X
SILLS-FRAME	**Aesthetic Defects**	E1. Rupture	X	**Physical Defects**	F1. Distortion-Breaking of Fasteners	-
		E2. Smooth Pollution	X		F2. Corrosion in Fasteners	-
		E3. Color Change	X		F3. Water Leakage	-
		E4. Mold fungus	X		F4. Partial Blanks	X
		E5. Cracking	X		F5. Sealing Deterioration	X
		E6. Swelling	X		F6. Shattered Glass	X
		……			F7. Heat problem	X
	Failures in Design	X	**Installatıon Failure**		**Using Failure**	**X**

Scoring System: 1: Excellent (no damage) 2: Good (damage that can be easily corrected) 3: Moderate (usable - maintenance required) 4: Bad (parts replacement required) 5: Very bad (parts cannot be replaced, cannot be used See Table: List of design, construction, usage failure

Table 17. Scoring examined windows

Window Code	Direction	Defect Degree					Total
		1	2	3	4	5	
P1	Southeast				X		
P2					X		
P3				X			
P4				X			
P5					X		
P6					X		
P7				X			
P8				X			
P9				X			
P10				X			
P11				X			
P15					X		
P16					X		
P17				X			
P18				X			
P19				X			
P20					X		
P21				X			
P22				X			
P23				X			
P24				X			
P25				X			
Total		**0**	**0**	**15**	**7**	**0**	**22**
P32	Northwest			X			
P33				X			
P34				X			
P36				X			
P37				X			
P38				X			
P39				X			
P40				X			
P41			X				
P42			X				
P43			X				
P44			X				
P45			X				
P46			X				
P47				X			
P48				X			
P49				X			
P50			X				
P51			X				
P52				X			
P53						X	
P54				X			
P55				X			
P56				X			
P57					X		
P58				X			
P59				X			
P61			X				
P62					X		
Total		**0**	**7**	**18**	**2**	**1**	**28**
P28	South west				X		
P29					X		
P30				X			
P12				X			
P14				X			
Total		**0**	**0**	**3**	**2**	**0**	**5**
P13	Northeast					X	
P31				X			
P26						X	
P27					X		
P35						X	
P60					X		

Consequently, partial gaps and loss of aesthetic value have been experienced. It has been found that most of the strip between the casing and the sash have been removed or never used, due to the demand of the user and construction failure. Therefore, heat losses occur. Corrosion was detected by invisible fasteners. In particular, protrusion of glass nails over the fixing lath presents both fixing problem and aesthetically unfavorable situation. Due to improper maintenance and environmental conditions, the level of contamination on the frame and sash was determined as 90%. Condensation has been detected on the glass of a window.

All of the aforementioned aesthetic damages were observed on the frame and sash. Smooth and intense contamination was observed on glass surfaces where there was no continuous cleaning (P2). Only one window glass showed condensation (P61). As a result of the inspections, the main reason for the damage is the lack of continuous maintenance depending on the environmental conditions or the defective/ inadequate maintenance.

Table 18. Criteria for evaluation

Evaluation Criteria- Main Criteria and Sub- Criteria	
Structural Performance	Structural stability
Durability	Security
Physical performance	Health
	Air impermeability
	Water impermeability
	Heat performance
	Sound impermeability
	Noise control
Ecological performance	Natural ventilation
	Solar Control
	Use of recyclable materials
Cost	
Aesthetic	Appropriate materials and details for the historical building
	Suitable color and textured material

It was found that the deteriorations on the façade of the building facing the sea were more severe and the deteriorations were observed on the lower frame and planted drip. As for the level of deterioration where decay was observed, the lower part of the sash fell and the window became unusable (Table 12-13). The sash must be replaced. Again, 95% of the windows in this direction showed intense blistering on the outer surfaces. For this reason, the amount of deterioration was high. Intense cracking and crevices were found on the exterior. Breaks and disintegration were also observed in glass laths. Depending on the cross-section, the heat permeability level was quite high. The glass cannot be changed as the cross section cannot be increased.

Basic and sub-criteria have been determined to be used within the scope of the evaluation by using Table 18. The maintenance plan was chosen to evaluate the criteria of heat impermeability, cost, aesthetics, and durability, as it did not impair the originality of the historical building. Since the building is a historical building, each maintenance process should be effective in the preservation of the original value of the building. Particular attention has been paid to the fact that maintenance of each component of the window system, which is part of this, should be taken into account. It is thought that the energy consumption of the building would be reduced by preventing heat escape within the windows, which affects the energy performance of the building to a great extent, especially during the winter months and hence, causes intensive use of heating systems. The cost criterion is important for the selection of the most effective and necessary solution in the long term with the most appropriate budget.

With the completion of information collection and determination of evaluation criteria steps, the maintenance phase for the window being studied and the selection of the alternative can be started.

Maintenance alternatives based on selected criteria are as follows:

1. Cleaning, sanding, puttying and painting the frame,
2. Placing insulation strips on the edges of the frame to increase the heat impermeability; replacement of fixing elements such as nails; replacement of the necessary glass laths; sanding, pasting and painting the whole window; repairing the drainages,
3. General cleaning of the frame; removing the damaged parts and replacing them; removing all window slats; closing the connection points between the frame and the rough structure with silicon; installing the planted drip on the frame for removal of the water from the frame; renewing the opening and closing mechanism, and applying weather-strip to ensure impermeability.
4. General cleaning of the frame, removing damaged parts and replacing them, removing all window laths, closing the connection points between the casing and the rough structure with silicon, installing the planted drip on the casing to remove water from the casing, renewing the opening and closing mechanism, and increasing the thickness of the glass by replacing the available one with the thicker glass to increase heat insulation, and replacing the lath due to the increase in glass thickness. As the area where the lath will be fixed will be narrower, the lath detail will be changed and a different lath section will be required by turning over the sash.
5. Completely changing the window for heat, sound, water, durability, aesthetic criteria to make the most ideal window system.

Table 19 shows the comparison of 5 maintenance options recommended for the window system analyzed. These 5 alternatives were examined according to the criteria, and the A1, A2, A3 alternatives were evaluated. Option A4 proposing replacement of the glass was eliminated during the preliminary evaluation stage due to the fact that this option increases cost, and the thickness of the cross-section of the sash cannot support the load of this glass, which creates security problem, The option A5 was also eliminated due to the cost increase (Table 19). As a result of the elimination, alternatives A1, A2, A3 satisfying most of the criteria were chosen for evaluation purposes.

After creating the hierarchy table in Figure 2, alternatives were questioned according to the criteria with the help of Super Decisions program. Cross-queries generated by the program was answered by relevant experts.

Table 19. Evaluation of alternatives in terms of selected criteria

Alternatives	K1. Heat performance	K2. Water impermeability	K3. Durability	K4. Aesthetic	K5. Cost effective
A1				X	X
A2	X	X	X	X	X
A3	X	X	X	X	X
A4	X	X	X	X	
A5	X	X	X		

Saaty (2006) scored the criteria as follows. Support was obtained from experts in weighting the criteria [21]. Points to be given to the criteria are as specified below:
1 point=equally important
3 points = moderately significant
5 points = strongly important
7 points = very important
9 points - absolutely significant
2,4,6 points = intermediate values (used when there are small values between two elements)

According to hierarchy in Figure 2, each criterion for Aim was compared in pairs. At the end of the comparison, a paired comparison matrix was formed on the basis of the scores obtained from the expert views.

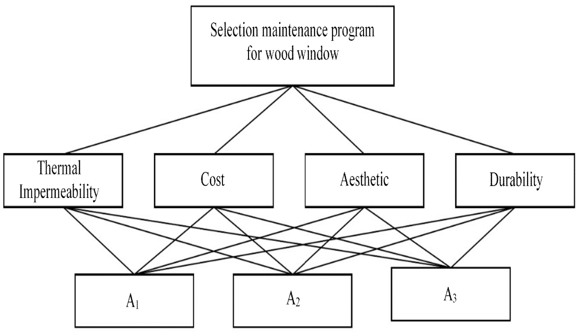


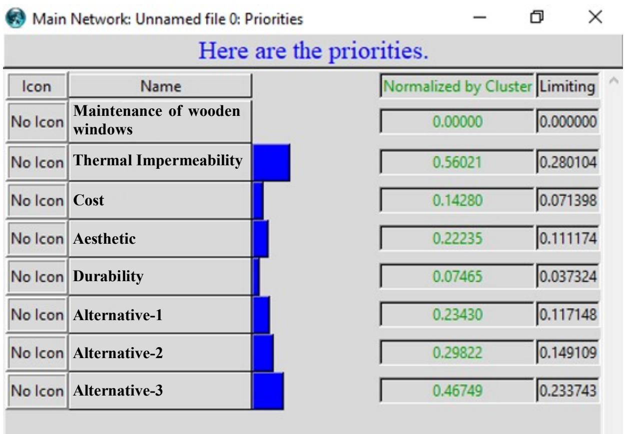
Figure 2. A hierarchical tree selection maintenance program for wood window

Table 20. Binary comparison matrix of criteria for selected window

Aim	Heat Impermeability	Cost	Aesthetic	Durability / Security
Heat Impermeability	**1**	5	3	5
Cost	1/5	**1**	2	3
Aesthetic	1/3	1/2	**1**	3
Durability/ Security	1/5	1/3	1/3	**1**

Table 20 shows the criteria to be identified by the expert and their pairwise comparison. Table 21 shows the result of Super Decision program. All values were evaluated with the answers given to cross-questions comparing the two criteria of the Super Decision program. Then the alternatives were evaluated with cross-questions considering the aforementioned criteria, and the final result was reached. Since heat impermeability is a very important factor in terms of criteria, it is concluded that the 3rd alternative should be selected as a maintenance and repair method.

Table 21. Comparison of alternatives for selected window in Super Decision program


Main Network: Unnamed file 0: Priorities

Here are the priorities.

Icon	Name	Normalized by Cluster	Limiting
No Icon	Maintenance of wooden windows	0.00000	0.000000
No Icon	Thermal Impermeability	0.56021	0.280104
No Icon	Cost	0.14280	0.071398
No Icon	Aesthetic	0.22235	0.111174
No Icon	Durability	0.07465	0.037324
No Icon	Alternative-1	0.23430	0.117148
No Icon	Alternative-2	0.29822	0.149109
No Icon	Alternative-3	0.46749	0.233743

5. RESULT

70% of the energy losses in buildings occur due to the faulty design of the facade or performance losses over time. Window systems covering the gaps on the facade are the areas where these losses are most intense. Determination of design, construction, usage and time-related failure in existing wooden window systems and preparing a maintenance plan for this will reduce energy consumption and provide resource efficiency instead of demolishing and destroy.

In this study, the possible defects on the wooden window systems were listed with a wide literature review and the data obtained from the observations made by the expert for the detection of these defects were recorded in the control lists. In the study, a method was developed based on the maintenance alternatives listed before and according to the degree of defects. This method has been applied to the window systems of a building with historical value and used for educational purposes. According to the data obtained from 62 wooden window systems examined, it was concluded that defects occurred due to environmental conditions, improper use and maintenance.

In these window systems, which have been used for more than 20 years, there is a big difference between the deterioration rates between the façade facing the sea and the façade facing the road. It was observed that the decay, swelling and rupture rates were higher on the sea-facing façade and that the lower part of the sash of the window P26 was broken and became unusable due to decay. In other windows, the application of a thick paint layer and swelling of the thick paint layer on surfaces exposed to strong wind caused damage on the unprotected surfaces. Due to the lack of regular maintenance, this damage has increased the effect level and has reached a level requiring serious interventions. The proposed maintenance was evaluated according to the criteria of heat incompatibility, cost, aesthetics, and durability. The arrangement of the windows differs according to the usage of the examined places as offices and classrooms. While the lower and upper sashes of the classrooms are arranged as fixed and openable respectively, windows of the office spaces are designed as an openable sash on the top section and fixed window at the upper part.

Due to the extreme height, cleaning problems are experienced in both cases. There is no windowsill in the original windows and inside there is a marble window board. The original window frame-sash sections of the building are thin so the space between the double glazing cannot provide sufficient thermal insulation. The heat impermeability criterion has been prioritized within the scope of alternative selection criteria. The cost has been considered as the second most important issue wherein it is aimed to satisfy all desired conditions economically. The aesthetic criterion is considered as 3rd most significant issue where the objective is to apply the maintenance process without disturbing the originality of the historical structure. The durability criterion means ensuring safety in a building with a high number of students. All of these criteria were determined by comparing them with each other via the computer-based Super Decision program of AHP, after which the significance of the obtained criteria was compared with alternatives to choose the most suitable option.

The method is simple and practical. With this method, the best option can be chosen among the maintenance alternatives developed by taking the requests of the users and operators into consideration. Storing the data in the checklist will also be a guide for future maintenance and repair work.

6. CONCLUSION

Making proper maintenance and repair plans for the window systems of existing buildings reduces energy consumption and ensures resource protection. The largest energy consumption in existing building occurs in the building façade, windows and doors. In this respect, window systems are evaluated from very different aspects such as energy consumption, resource, aesthetic value etc.

Maintenance and repair decisions must be related by providing information about energy losses, safety, aesthetics, etc., especially by minimizing the energy consumption, by providing information to the user with the guide created by the local authorities, in certain periods. This method when used by local authority have many advantages such as reducing energy consumption, and do not change character of the building (by choosing different colors, choosing different size windows, etc.).

The study starts with recording the current state of the building via preliminary examination. Several information about windows are written on prepared tables such as material, dimensions, on which floor and in which direction they are placed, etc. This preliminary information is important in finding the rate of impact on the severity of the defects. All of them will affect the selection among the maintenance alternatives to be determined later. For this reason, preliminary assessment should be made accurately and completely. Then the preliminary information phase of the database is completed with visuals showing the deterioration status of the current window. According to the information obtained, the defects are scored, and after the analysis is made in accordance with the determined criteria, a selection is made among the maintenance alternatives according to the total score.

In the study, the defects in 60 wooden windows of a historical educational building were investigated. As a result of the negotiations with the directors of the building, the main reason of the defects in the windows is identified as the size of the building and the high floor heights and environmental conditions of the building located at the seaside. A method has been proposed for the selection of the appropriate alternative depending on the degree of deterioration among the maintenance alternatives for the windows by prioritizing with all these criteria, and this proposed method has been applied on a selected window system. It was seen that the obtained result coincides exactly with the desired one. This proved the correctness of the proposed method.

As a result of the study, it was seen that wrong maintenance applications increased the deterioration rates in the examined window systems. Accurate determination of the maintenance planning periods according to the environmental impacts may extend the service times of the existing windows. Prioritizing the criteria needed to be satisfied by the windows in the existing building stock and the maintenance methods to be selected can both increase the comfort conditions, extend the service time and provide energy and resource efficiency.

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Authors' Contribution

ÖE: investigation, literature review, methodology, data analysis, writing and finalizing.

MO: investigation, literature review, drawings, finalizing

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The authors declare that this document does not require an ethics committee approval or any special permission.

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The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

REFERENCES

[1] S. S. Liu and G. Ramadhan, "Conditioned –Based Building Maintenance Strategy Selection Using Constraint Programming," Facility Maintenance and Management, pp. 345-351, 2017.

[2] M. Y. L. Chew, S. S. Tan, and K. H. Kong, "Building Maintainability-Review of State of the Art," Journal of Architectural Engineering, pp 80-87, 2004.

[3] A. Santos, M. Vicente, J. de Brito, I. Flores-Colen, and A. Castelo, "Inspection, Diagnosis, and Rehabilitation System of Door and Window Frames," Journal of Performance of Constructed Facilities, vol. 31, no. 3, pp 04016118-1-12, 2017.

[4] M. Macarulla, N. Forcada, M. Casals, M. Gangolells, A. Fuertes, and X. Roca, "Standardizing housing defects: classification, validation, and benefits," Journal of Construction Engineering and Management, vol. 139, no. 8, pp. 968-976, 2013.

[5] J. Morgado, "Inspection and maintenance plan for roofs in current buildings," Ph.D. thesis, Instituto Superior Técnico, Universidade Técnica de Lisboa, Lisboa, Portugal (in Portuguese), 2012.

[6] I. Flores-Colen, and J. de Brito, "Plan of inspection and maintenance of a school building—A case study." Proc., QIC, National, Meeting on Quality and Innovation in Construction, LNEC, Lisbon, Portugal, 569–580, 2006.

[7] H. Lind, and H. Muyingo, H, "Building maintenance strategies: planning under uncertainty," Property Management, Vol. 30, no. 1, pp. 14-28, 2012.

[8] Lopes J.N.P., Morgado V., 2012, Inspection and Maintenance Plan for Roofs in Current Buildings, Instıtuto Superior Tecnico.

[9] I. Flores-Colen, and J. de Brito, "A systematic approach for maintenance budgeting of buildings façades based on predictive and preventive strategies," Construction and Building Materials, vol. 24, no. 9, pp. 1718-1729, 2010.

[10] A. Straub, "Using a condition-dependent approach to maintenance to control costs and performances," Journal of Facilities Management, vol 1, no. 4, pp. 380-395, 2002.

[11] M. Riley, A. Cotgrave, "The Technology of refurbishment and Maintenance," Palgrave Macmillan. Basingstoke, 2005

[12] T. Damen, L K. Quah, and H. C. M. van Egmond, "Improving the art and science of condition-based maintenance systems", in Quah, L.K. (Ed.), Proceedings of the CIB W070 Symposium, The Way Ahead into the Millennium, Singapore, McGraw-Hill, Singapore, pp. 141-8, 1998.

[13] M. H. Hermans, "Deterioration characteristics of building components: a data collecting model to support performance management," Technische Universiteit Eindhoven, 1995.

[14] L.W. Masters, (Ed.), "Problems in service life prediction of building and construction materials" vol. 95, Springer Science and Business Media, 2012.

[15] S. Madureira, I. Flores-Colen, J. de Brito, and C. Pereira, C, "Maintenance planning of facades in current buildings," Construction and Building Materials, no 147, pp. 790-802, 2017.

[16] R. A. Munro, M. J. Maio, M. B. Nawaz, G. Ramu, D. J. Zrymiak, "The Six Sigma Green Belt Handbook," Wisconsin: ASQ, 2007.

[17] P. Pande, and L. Holpp, “What is six sigma?,” New York: McGraw-Hill, 2001.

[18] M. Ben-Daya, S. O. Duffuaa, A. Raouf, J. Knezevic and D. Ait-Kadi, “Handbook of maintenance Management and Engineering,” Springer, London, 2009.

[19] Z. Sönmez, “Six Sima methodology process improvement and an application in service sector,” Istanbul Kultur University, Master thesis, İstanbul, 2013.

[20] L. A. Zadeh, “The concept of a linguistic variable and its application to approximate reasoning—I,” Information sciences, vol. 8, no.4, pp. 301-357, 1975.

[21] T. L. Saaty, and L. G. Vargas, L. G, “Decision making with the analytic network proceses Economic, Political, Social and Technological Applications with Benefits, Opportunities, Costs and Risks, Springer Science+Business Media, LLC, New York, USA, 2006.

[22] T. L. Saaty, “How to make a decision: the analytic hierarchy process,” Interfaces, vol. 24, no. 6, pp. 19-43, 1994.

[23] G. Pahl, W. Beitz, and K. Wallace, “Engineering Design: A Systematic Approach,” London: Springer, 1996.

[24] M. H. Tooley, and Knovel, “Design Engineering Manual (1st ed),” Amsterdam; London; Boston: Butterworth-Heinemann, 2010.

[25] T. Tomiyama, P. Gu, Y. Jin, D. Lutters, C. Kind, and F. Kimura, “Design Methodologies: Industrial and Educational Applications,” CIRP Annals - Manufacturing Technology, vol 58, no.2, pp. 543-565, 2009.

[26] D. Shetty, “Product Design for Engineers,” Boston: Cengage Learning, 2016.

[27] G. Atkinson, “A century of defects.” Building,” 54–55, 1987.

[28] CIB Working Commission W86, “Building Pathology: A State-ofthe Art Rep, International Council for Building Research Studies and Documentation,” Rotterdam, The Netherlands, 1993.

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