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Noise Emission from Building Integrated Wind Turbines: A Case Study of a Tall Building

İlker KARADAĞ*[1], Emre KURUÇAY[2]

Abstract

Tall buildings have the ability to produce wind energy, having been exposed to relatively high airflow speeds at a far distance from ground levels. However, with the introduction of wind energy into urban areas, there are many concerns. These include especially environmental noise impacts since the wind turbines will be located in dense urban areas where tall buildings are mostly located. Therefore, this increasing use of wind energy in the built environment has led to the publication of up-to-date regulations that limit noise levels for wind farms in many European countries. At this point, the following three aspects should be considered for noise emission: the noise source, the distance from the source, and the sound pressure level of the noise source. The choice of wind turbines for urban environments should, therefore, be compatible with low noise levels. In addition, careful positioning of turbines is also important (avoid locations where wind conditions are unfavorable, avoid sensitive places, i.e. areas at which noise levels must be low). It was necessary to calculate the noise in strong winds because the noise from a wind turbine rises with wind velocity. For the measurement of noise emitted from the wind turbine, two potential solutions were proposed until now; either it could be measured in a wind tunnel or it could be measured in the natural wind outside. However, in the early design stage, these types of measurement methods are mostly not preferable due to high financial requirements and long measurement processes. Hence, in this study, wind turbine noise is simulated via software. A case study of a tall mixed-use tower is chosen and the environmental noise distribution due to the wind turbine located on the roof of the tower is simulated. The results may provide an important guideline for architects looking for an acoustically comfortable way to integrate wind turbines into their buildings in the early design stage.

Keywords: building-integrated wind turbines, environmental noise, tall buildings

1. INTRODUCTION

Due to the increasing need for energy and the negative impact of existing fossil fuels on the environment, the use of alternative energy sources is gradually increasing. Active use of wind is the fastest-growing alternative among sustainable energy sources. Despite the global economic

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crisis of 2009, wind turbine investments continued to increase in the world and our country [1].

In our country, there are many wind turbine farms with a total capacity of 801 MW and the construction of the farm with a total capacity of approximately 500 MW continues.

Increasing active use of wind has led to the creation of up-to-date regulations that set noise limits for wind farms in many European countries where its use is widespread (England, Germany, the Netherlands) and explains how to measure and evaluate noise.

The sound emitted from the wind turbines is significantly different in structure and level from the one emitted by large-scale power plants that categorized as industrial sound sources. Wind turbines with their unique ambient sound character are mostly located in rural areas or the fields far from the urban areas. Although noise can be a problem for the population living near wind turbines, as the distance increases, the ambient or background noise arising from the nature of the wind is able to mask the sound produced from the turbine [2]. However, this distance cannot be secured easily in a dense urban environment.

Tall buildings are widely seen forms of urban areas which require too many activities with plenty of spaces on a low base area and too many floors being useful to use. In addition, they have major effects on local wind characteristics across the urban area near the site. In the urban environment surrounding tall buildings, winds are usually strengthened at the roof level given the complex aerodynamic structures generally associated with this type of building [3].

Acceleration of the local air flow at the roof level due to the separated flow makes it feasible to integrate small-scale wind turbines that are capable of harnessing wind energy. These wind turbines can be integrated into the building design. But in most cases, it is not easy to integrate the turbine into an existing building. Therefore, mounting the turbine to the roof when structural requirements are fulfilled is the most viable and common option [4].

2. SOURCES OF WIND TURBIN NOISE

Sources of sounds emitted from the wind turbines are classified into two headings: mechanical sound (1) and environmental sound (2).

2.1. Mechanical Sound

The relative interaction of mechanical components with each other is a result of sounds and dynamic responses between components. The mechanisms that cause these noises can be listed as follows: gearbox, generator, yaw mechanism (the system that directs the turbine in the direction of the wind), auxiliary equipment (such as hydraulics) and cooling fans [5].

Because the sound emitted is correlated with the mechanical and electrical component rotation, it appears to be tonal (at a common frequency), but a broadband component may also be available for the sound. For instance, the rotational frequencies of shafts and generators and the network frequencies of gears may convey pure tones.

Additionally, rotor, the hub and tower can function as loudspeakers that transmit and subsequently emit mechanical sound. This permeation can take place through the structure as well as through the air gap. Air-borne transmission indicates the sound is directly dispersed from the element's surface or from the interior [5]. On the other hand, in structural transmission (structure-borne) sound first passes through the structural elements and then spreads in the air. For example, Figure 1 comprehensively shows the transmission path for a 2 MW wind turbine and the sound power levels for each component. When examined in detail, it is seen that the main source of mechanical sounds is the gearbox. This component emits sound from the nacelle surfaces and the component surrounding the mechanical parts.

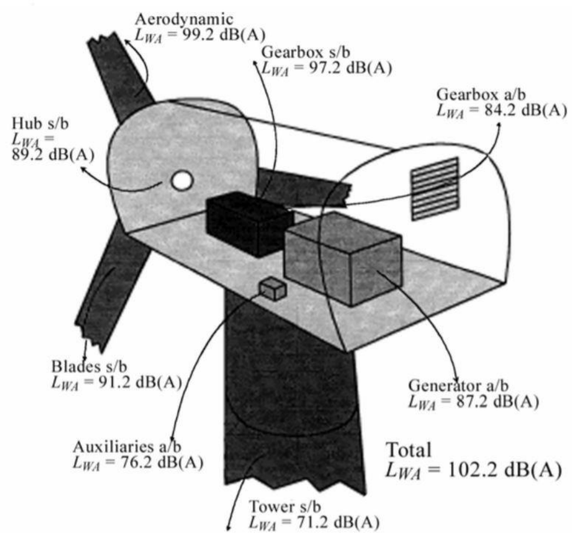


Figure 1 Parts and total sound power level of a wind turbine, indicating transmission paths of structure-borne (s/b) and airborne (a/b) [5].

2.2. Aerodynamics Sound

The largest component of wind turbine acoustic emission is usually aerodynamic broadband sound. The airflow around the blades creates it. As seen in Figure 2, many complex flow phenomena arise, each of them can produce a certain amount of sound.

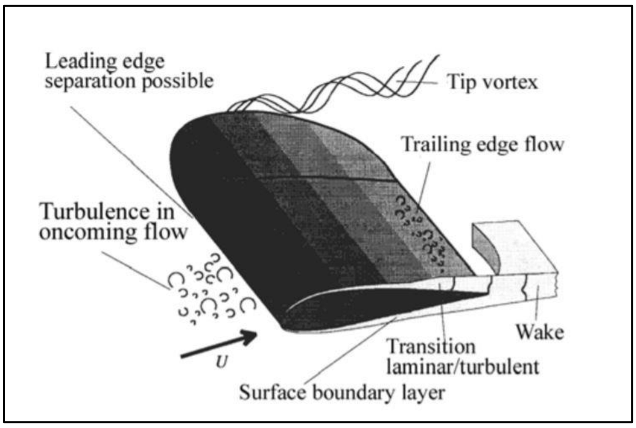


Figure 2 Schematic of Flow around a Rotor Blade [5].

With rotor velocity, aerodynamic noise typically increases. Table 1 indicates some aerodynamic sound generation mechanisms that should be noticed [5]. These mechanisms are grouped under 3 separate headings:

II.I. Low-Frequency Sound: In the low-frequency section of the sound spectrum, sounds encounter local flow disconnections due to reasons such as the flow around the rotating turbine blade turbine tower, the change in wind speed, or the fall of the track left by other blades.

II.II. Sound from Incoming Flow Turbulence: Varies depending on the size of atmospheric turbulence which induces local variations in force and local pressure across the blade.

II.III. Wing Section Originated Sound: The sound created by the air flow which continues across the full surface of the wing is included in this group. This sound type is characteristic of a broadband nature, but tonal components could also be seen owing to the choice of cut-out trailing fins (figure 3) or gaps or tears that could cause infiltration.

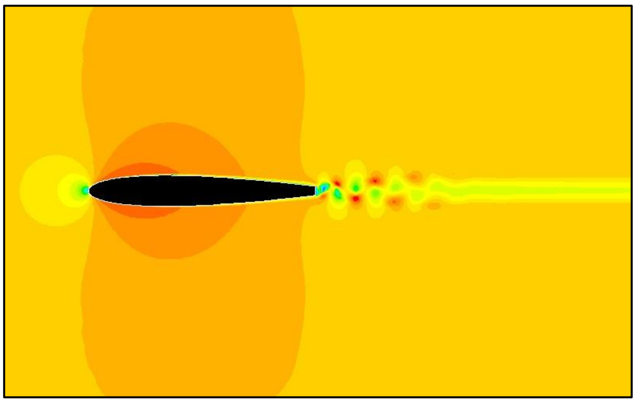


Figure 3 Eddies that cause noise originated from the blunt end of the wing trailing edge [6].

Table 1
Aerodynamic Sound Mechanisms of a Wind Turbine [5]

Type or indication	Mechanism	Main characteristics & importance
Low-frequency sound		
Steady loading noise; dteady thickness noise;	Rotation of lifting surfaces or Rotation of blades	Frequency is correlated to blade passing frequency which is not significant at current rotational velocities

Table 2 Continue

Unsteady loading noise	Passage of blades through tower speed	Frequency is correlated to blade

	deficit or wakes	passing frequency, low in cases of upwind rotors, though possibly contributing in case of wind farms
Inflow turbulence sound	Blades interacting with atmospheric turbulence	Contributing to broadband noise; not yet fully quantified
Airfoil self-noise		
Trailing-edge noise	Boundary layer turbulence interacting with blade trailing edge	Broadband, main source of high frequency noise (770 Hz < f < 2 kHz)
Tip noise	Tip turbulence interacting with blade tip surface	Broadband; not fully understood
Stall, separation noise	Turbulence interacting with blade surface	Broadband
Laminar boundary layer noise	Interaction of Non-linear boundary layer instabilities with the blade surface	Tonal, can be prevented
Blunt trailing edge noise	Vortex shedding at blunt trailing edge	Tonal, can be prevented
Noise from flow over holes, slits and intrusions	Unstable shear flows over holes and slits, vortex shedding from intrusions	Tonal, can be prevented

3. SIMULATING THE SOUND PROPOGATION

Since sound is measurable, limits can be drawn in establishing planning criteria related to noise. The emission and propagation of wind turbine-induced noise can be simulated. In this simulation, surrounding structures, landscape and roads are also taken into account. (Asphalt and concrete are known to be highly reflective materials in terms of acoustics).

In a study conducted by the National Renewable Energy Laboratory [7], noise emission measurements were made for a turbine with a diameter of 7m and a capacity of 10 kW, and a distance of 54 m was taken between the microphone and the rotor. As a result of the study, it has been observed that the noise generated by the turbine is almost not perceived with increasing distance and does not exceed the rural background noise level at most different wind speeds. Urban background noise is much higher than the background noise considered in the study, even at low wind speeds.

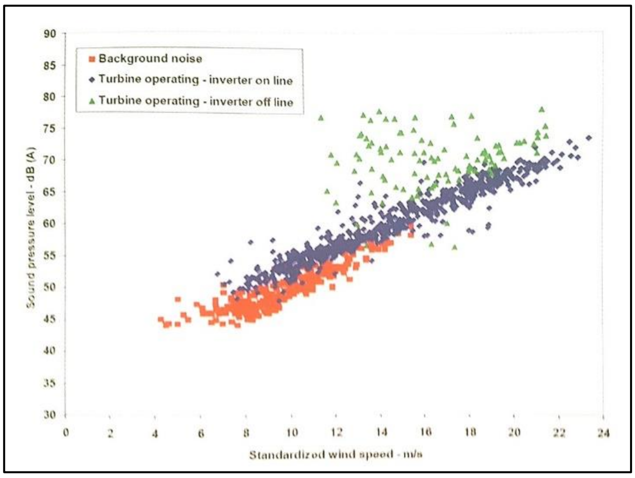
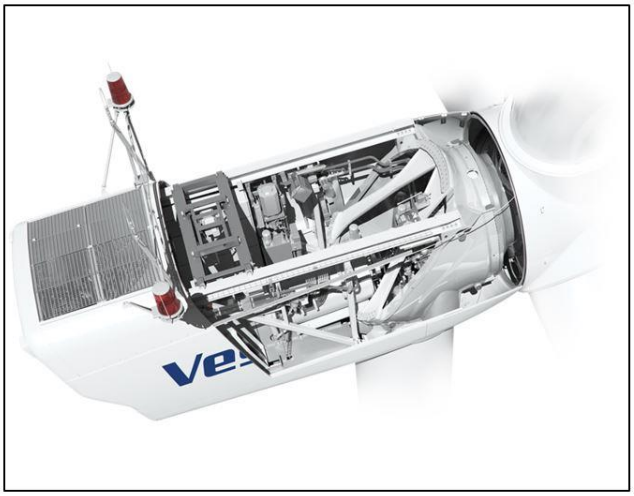


Figure 4 Noise emission measurements for a turbine with a diameter of 7m and a capacity of 10 kW, data taken at a distance of 54 m from the microphone [7].

If the wind speed is low, the noise level from the wind turbine remains minimal. However, if the turbine is exposed to wind speeds between 4m / s and 30m / s at the body height, the sound power level increases monotonously, the noise specifications of the Vestas 3MW turbine can be seen in Figure 5.



U_s m/s	4	5	6	7	8	9
Lw dB(A)	97.9	100.9	104.2	106.1	107.0	106.9

Figure 5 Sound power levels of the Vestas 3 MW wind turbine at different wind speeds [8].

When any turbine runs freely, that is, when the Inverter is off, it creates much more aerodynamic noise. While the inverter is on, that is, while generating energy, a resistance occurs between the rotor (rotating part) and the stator (fixed part) that prevents the rotor from rotating in an uncontrolled manner.

Different wind turbines produce sound of significantly varying quality and level. In the past, noise was a serious issue for wind farms, and the cumulative impact of many turbines was causing serious problems. But technological advances and better analysis of the mechanisms that cause noise have paved the way for new production processes and quieter turbines. The best known of these are turbines that can operate at different speeds without gearbox, improvements in blade design, and low wing-tip speed ratios.

4. SIMULATION OF SOUND PROPAGATION AND DISTRIBUTION OF THE CASE STUDY

The 238m high Sapphire Tower was chosen for the case study to assess the noise emission and distribution of the building integrated wind turbine. In fact, this choice represents a possible situation because the structure to be integrated with the wind turbine must have a certain height and be free from turbulence caused by surrounding structures and topographic effects. A prototype wind turbine with a horizontal axis of 20m in diameter and 49m of hub height was selected for this study. Predictor Lima v.9 software was used during the analyzes, this software takes into account the frequency-dependent behavior and the scattering of the sound around the obstacles, which are of great importance in sound dispersion models (Figure 6).

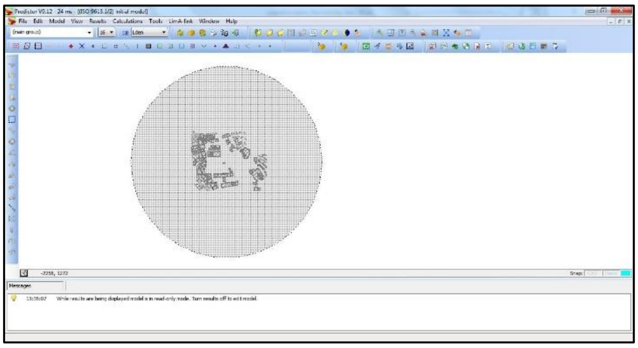


Figure 6 Graphical User Interface of the Predictor Lima v9.2 software.

In this study, the "wind turbine" object defined in the software based on the center point of the circle forming the turbine blade sweep area was used as the sound source. In this way, the availability of such an object made it possible to define a much more detailed sound source instead of the standard point source.

In order to create a consistent simulation of wind turbine noise, the "wind turbine catalog" tool, which contains values taken from manufacturers, was used. Data on turbine selection and sound power levels are shown in Figure 7. The Lw_{min} value for the selected turbine is 99.9 dB (A), and the Lw_{max} value is 103.2.

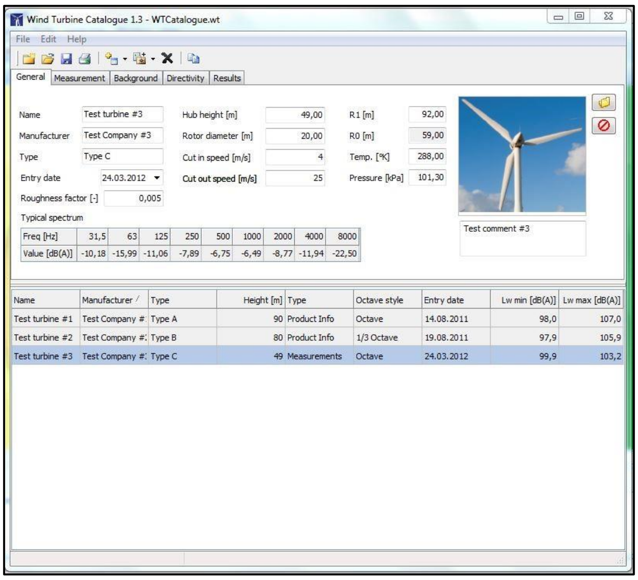


Figure 7 Predictor Lima v9.2 wind turbine catalog-turbine selection and sound power levels.

In the second phase of the study, the selected vertical axis wind turbine was integrated into the roof of the building and primary estimates were obtained. Subsequently, two different grid options in the program were used to determine the buyers and to create a calculation grid. The first of the grids was taken in the horizontal plane using the "grid tool" and at a height of 4m from the ground. The second grid was created using the vertical grid tool on the fronts of the surrounding structures, which were considered critical.

Since it was predicted that the near-field perceptions of sound would not be affected much by the wind regime in the urban scale, the effect of wind speed and direction was not determined from climate data. Instead, 5 different possible scenarios were discussed. In these scenarios, wind speed played a role as the determining factor. Simulations were conducted for wind speeds of 4 m/s, 8 m/s, 12 m/s, 16 m/s, 20 m/s, respectively. These speeds were determined by reference to the operating range of the selected wind turbine, 4 m / s (cut in speed) and 25 m / s (cut out speed). As a result of the simulation, facade noise maps were drawn on the surrounding buildings (4. Levent - Büyükdere Boulevard). The graphs where sound pressure levels are obtained for 5 different scenarios are given below.

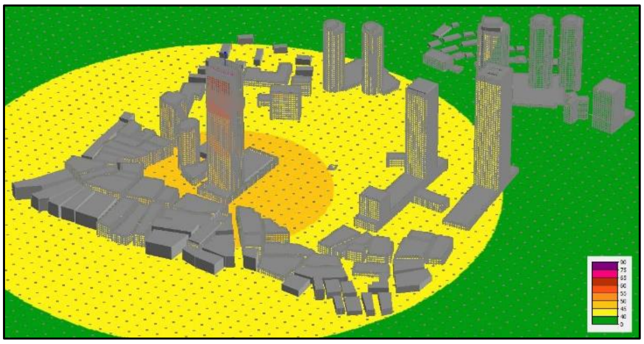


Figure 8 Axonometric view of sound pressure levels on façades (wind speed: 4 m/s).

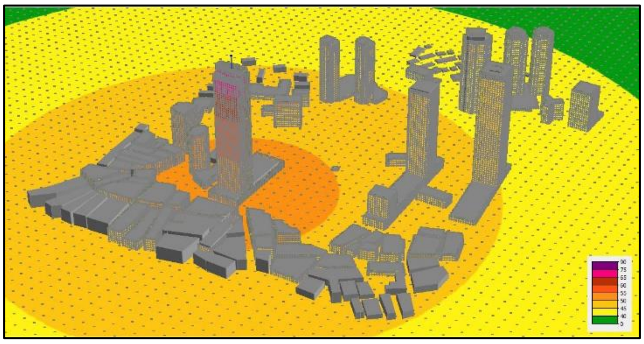


Figure 9 Axonometric view of sound pressure levels on façades (wind speed: 8 m/s).

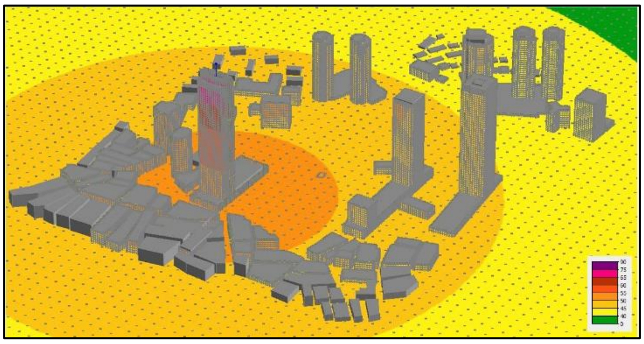


Figure 10 Axonometric view of sound pressure levels on façades (wind speed: 12 m/s).

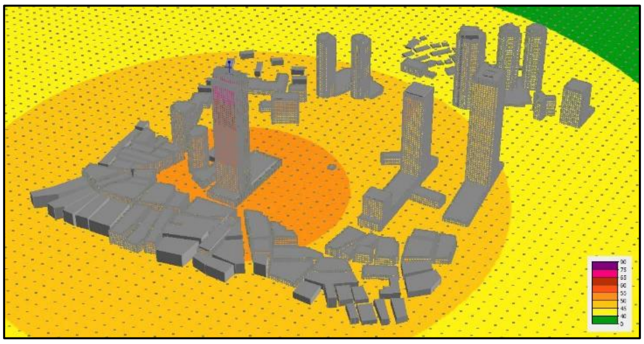


Figure 11 Axonometric view of sound pressure levels on façades (wind speed: 16 m/s).

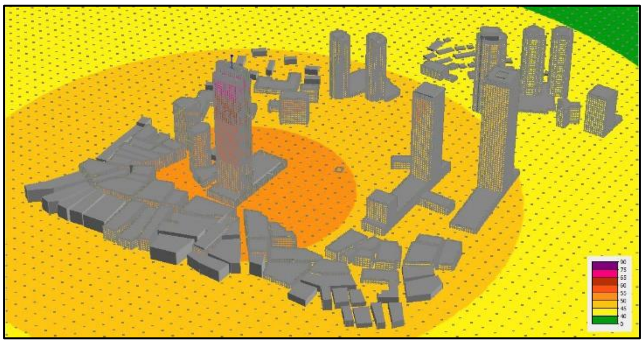


Figure 12 Axonometric view of sound pressure levels on façades (wind speed: 20 m/s).

5. RESULTS & CONCLUSION

A wide spectrum of conclusions can be drawn from numerical analysis:

- A structure can act in a number of different ways in terms of emitting noise: it can focus sound waves close to the structure: it can reflect sound waves away from the building surface: it can act as a noise barrier for structures in the vicinity: and it can absorb sound energy.
- For a structure with an aerodynamic form: the highest sound pressure levels will likely occur perpendicular to the spin plane of the horizontal axis wind turbine. In the case study discussed, critical sound pressure levels were observed in the floors just below the turbine (65-75 dB).
- Even for a completely reinforced concrete structure, the maximum sound pressure levels measured at 4 m above ground plane for the selected turbine will not exceed 50 dB (A), which complies with even the strictest noise standards and does not pose a problem in terms of planning criteria.

For interior receivers (e.g., within an aerodynamic building), the problem of focusing sound waves requires a special numerical analysis for acoustic improvements, and possibly also for turbine façades. Sound absorbing materials such as acoustic plaster (acoustic plaster), eps (expanded polyurethane foam) and fiber panels (fiberboard) can be used and additional layers can be specified for glass surfaces. This improvement will also minimize problems with sound propagation, as it will reduce sound pressure levels by approximately 3 dB (A) in areas close to the ground plane.

For the selected urban location, the distance to the closest buildings varies between 15m and 25m. The maximum sound pressure levels on the surrounding buildings were measured at the level of 50-55 dB (A) and on the building facades just behind the turbine. This value is below the frequently determined 55 dB (A) upper limit value for buildings located on commercial axes.

It is concluded that a special acoustic improvement is often necessary for facades and wind turbine integrated structures, especially in urban areas where commercial and residential areas are located.

In future studies, the acoustic properties of the mesh surfaces designed for security purposes that can be placed on the normal axis of the turbine rotor plane can be examined: the effect of sound absorption or screening can be analyzed. These surfaces may not match the integrity of the architectural design as it breaks transparency; however, this situation can be overcome by determining detailed design criteria and energy efficient aerodynamic design.

A combination of approaches that accommodate all of these improvements will ensure that the cumulative noise impact generated by building integrated turbine projects alone or combined with background sound levels remains within acceptable limits in terms of planning.

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The Declaration of Conflict of Interest/ Common Interest

“No conflict of interest or common interest has been declared by the authors”.

Authors' Contribution

The authors contributed equally to the study.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

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.

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