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ASSESMENT OF DAYLIGHTING PERFORMANCES OF CLASSROOMS: A CASE STUDY IN KIRKLARELI UNIVERSITY, TURKEY

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ABSTRACT

This study was conducted to evaluate the daylighting performances of classrooms. For this study, a classroom in Kayali Campus and two classrooms in Kavakli Campus of Kirklareli University have been selected. In these buildings, the illuminance levels have been measured and standards and design rules have been investigated. Modelling in the Velux Daylight Visualiar simulation program, the classrooms have been evaluated in terms of daylighting parameters. Consequently, window properties that can provide better natural lighting in the classroom have been identified. According to the measurements and the results of the simulation, daylight illuminance levels in these environments has been found to vary by directions. The buildings' orientation, the window openings on the facade of buildings and the shading elements should be designed at the point of the natural lighting idea by expert designers in the field.

Keywords: energy efficiency, daylighting, illuminance, classroom, school lighting, Turkey

INTRODUCTION

Energy is one of the most important parameters in understanding development and welfare level of countries. Furthermore, as in other countries, in Turkey it is the most important parameter that increases living standards besides economic and social development. The increase in energy consumption affects the balance of supply and demand and countries search for alternative ways to meet energy demands. Countries mostly use conventional energy sources to supply energy demands and this leads to environmental problems. In order to address this problem, renewable and alternative energy sources are sought. The usage of renewable and alternative energy sources prevents environmental pollution and plays an important role in preventing the dependence on other countries for energy resources. The usage of renewable and alternative energy sources contributes to an increase in labour force potential and mobilisation of a countries' internal resources due to the transfer of technology [1].

Buildings intensively consume energy and always need it. The energy consumption of buildings in the use stage differ from the construction stage and include warming, lighting, air-conditioning, hot water supply and the usage of electrical devices. The usage rates of these consumption methods differ depeding on the service type of the building. This variability in the buildings of educational institutions occurs as lighting, air-conditioning and supplying the energy demand of machines and devices in labs. Artificial lighting constitutes a high amount of energy demand in educational institutions [2]. So there is potential to generate energy savings through rehabilitations in lighting and its systems and their related energy supply. The natural lighting systems are considered as the best solutions to this issue.

Daylighting is often cited as a key component of green building and a type of lighting carried out by using daylight [3]. The term 'daylight' is used to refer to the totality of illumination provided by the sun and the sky [4]. Daylighting is the main lighting source used to enlighten the interiors of buildings from past to present. When daylighting is used correctly and appropriately, the users of the buildings can work and act easily and efficiently in a comfortable environemnt [5]. By using natural lighting systems, the lighting system load can be decreased by a significant amount. However, natural lighting can only be used when there is daylight. In educational facilities, especially in those that give dual-educational systems, there must be an alternative solution to carry out energy continuity because of the absence of daylighting. In this situation, engaging artificial lighting systems or hybrid renewable energy sources can be a solution.

This study firstly describes the components of lighting systems and investigates the usage of natural lighting equipment in buildings. For the transfer of daylight into the building, the sizes of windows, the position of windows and the orientation of buildings; for uniform light distribution in the interior environment, variables such as colour and reflection properties of spaces have been investigated. Later, the daylighting performances of a classroom in Kofcaz Campus and two classrooms in Kavakli Campus have been evaluated. In these places, the lighting levels have been measured and standards and design rules have been investigated. The classrooms have been evaluated in terms of daylighting parameters using the modelling capabilities within the Velux Daylight Visualiar simulation program. Consequently, window properties that provide better natural lighting in the classroom have been identified.

2. BENEFITS OF USING NATURAL LIGHTING IN EDUCATIONAL BUILDINGS

It is known that illumination affects the mood and motivation level of people. The proper design and selection of daylighting systems can significantly help in improving energy efficiency and reducing environmental pollution. It creates healthier learning environments that may result in increased attendance and improved grades in the case of school design [2,6,7]. When properly designed, windows, clerestories, and roof monitors can provide a large portion of the lighting needs without undesirable heat gain or glare. And therefore, electric lights can be turned off or dimmed in daylit spaces when the target illuminance is achieved by daylighting. Energy savings can only be achieved by implementing light controls, sensors and light dimmers for the lighting system of those daylit spaces [2,8,9].

The International Energy Agency (IEA) reports that 19% of electricity worldwide is used for lighting [10]. The usage of daylight in buildings significantly decreases the electric energy consumption [11,12]. For instance, it has been shown that artificial lighting of non-domestic buildings represents 50% of the energy consumption in Europe. It also has been shown that it is possible to reduce this consumption by between 30 to 70 percent by combining the use of artificial and natural lighting. Potential savings dependend on orientation, the size and shape of the window, and the shape and surface reflectance of the room. [8,11].

The use of natural lighting is an important element in modern architecture as it aids in creating a pleasant visual environment. Natural lighting is considered the best source of light for colour rendering [2,13]. The visual comfort related to the quantitative and qualitative aspects of the daylight significantly contributes to the well-being of pupils and thus leads to better school performances. A survey of more than 20,000 elementary school students and 100 schools in the USA confirmed this statement. It has been proved that students with the most natural lighting in their classroom progressed 26% faster in reading and 20% faster in mathematics [14].

3. ARCHITECTURAL DESIGN PARAMETERS OD BUILDINGS WHICH TAKE ADVANTAGE OF NATURAL LIGHTING

3.1. Windows

Classrooms are designed to receive light on a two facing facade. In this way, a more uniform distribution of daylight can be achieved in the classroom. Large window areas may provide good amounts of daylight and pleasant views [2]. Keeping the depth of rooms within 1,5–2,0 times of window head height provides adequate illumination levels and balanced distribution. With a reflective light shelf, this zone may be extended up to 2.5 times the head height. Keep window area to a 30–40% window-to-wall ratio. Band windows application which provide a more uniform spread of daylight in the classroom should be preferred. A vertical form of east and west windows should be chosen. For example, vertical fins or recessed windows. It is also useful to block early morning and late afternoon low sun on the north [14].

3.2. Lighting

Lighting is one of the most important of all building systems. Every school relies on lighting to provide an effective learning environment, which is one of the most critical physical characteristics of the classroom. The modern classroom is a space where a wide range of teaching/learning activities take place. These include traditional blackboard tasks, individual desk work, computer work, audio-visual presentations, fine arts, sewing, the use of visual aids on the walls and more. Adequate lighting is vital for sight-impaired students or for students who use dangerous equipment such as lathes or saws in shop classes. Key issues are visual comfort and providing appropriate horizontal illuminance for all the various tasks and activities that take place in the classroom [12].

Classroom lighting needs to provide teachers with the ability to change the lighting in response to the visual needs of each type of activity. Indoor lighting should achieve the desired appearance and ambience in the space as well as meet many other important functional and psychological needs. Educators have noticed how lighting affects students' behaviour, alertness and ability to learn. Classroom lighting plays a particular role because of the direct relationship between good lighting and students' performance. Bad lighting leads to discomfort and hyperactivity, while better lighting produces greater productivity. Teachers have also noted that lighting affected their own effectiveness in the classroom and their ability to handle the stress of the teaching profession. Lighting can have a significant impact both on student and teacher productivity [15]. One approach to classroom lighting that has gained wide acceptance in recent years is creating instructional spaces that rely on daylight for illumination. While natural illumination from windows and skylights is a preferred standard, most learning environments will require supplemental electric lighting. The Illumination Engineering Society recommends a minimum of one window per instructional space because it increases the quality of the educational environment [15]. It is evident that lighting and windows play a significant role in the achievements of students; however, daylight in some poorly designed instructional spaces may enter the room too directly and create glare, which can hinder learning.

Generally, when people sense the lighting system is causing visual discomfort, the problem is poor lighting quality. Integrating a building's daylight strategy with the electrical lighting system is critical to achieving energy savings. The type of lighting equipment selected for a school can increase energy efficiency. Other methods of enhancing the use of daylight while increasing the effectiveness of a daylight plan are: skylights, clerestory windows, roof monitors and a roof design that diffuses light throughout an area [16].

3.3. Colour of exterior and interior surfaces

In order to increase daylight's entrance into the building, light colours should be used on for windows' wings that direct the light and light shelves. Moreover, the elements used to reflect light must be made in a position to reflect the light to the ceiling. Wall and ceiling surfaces must be light coloured so that the light can be spread [14].

3.4. Recommended surface reflectances

Desirable reflectance according to Illuminating Engineering Society's recommendations: ceilings >80%; walls 50–70% (higher if wall contains window); floors 20–40%; furniture 25–45%. Use light-transmitting materials for partitions where possible. Use clear or translucent materials in the upper portion of full-height partitions. If this approach is taken in corridor walls, corridors may be adequately lit just by this spill light [14,15].

3.5. Building orientation

The most suitable direction for natural lighting are south and north. The north direction is not exposed to radiation, but can always get daylight in the same quality. In the west and east directions, the sun radiates in horizontally and makes it difficult to control. In the south direction, the effect of the sun

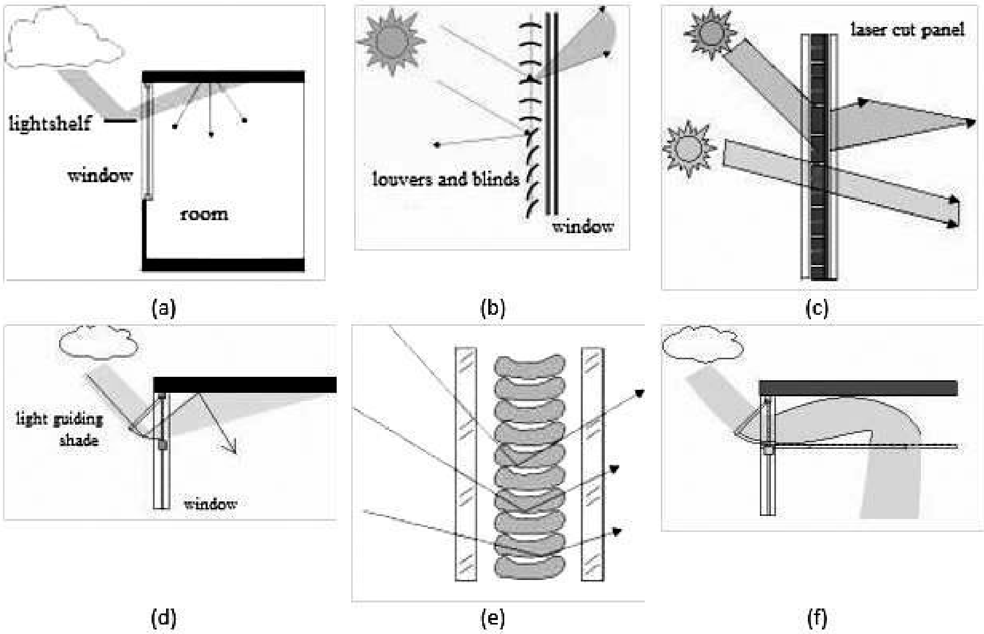

Fig 1. Daylighting systems using direct sunlight
(a) Light shelf system (b) Window shade and blind system (c) Laser cut panels (d) Light guiding shade
(e) Light guiding glass (f) Anidolic ceiling

is permanent and sun rises at a right angle compared to the west and east directions. Therefore, it is easy to control.

3.6. Building form

In order to benefit from natural lighting, the rate of surface size should be decreased. More exterior front areas leads to more opened windows. However, the decrease in the rate of surface size will increase the heat loss and earnings via the building's shell. It is necessary to strike a balance between both parameters. Moreover, while designing the plan of construction block actions supplying self-shadow to east and west directions can be made, fronts can be deepened. If this cannot be carried out, unwanted sun penetration and shadowing elements (blinds, light shelves and solar cutters) can be decreased. It is preferable that the shadowing elements are openable and closable.

3.7. Use north facing monitors

In case the design did not permit south-facing roof monitors, north-facing roof monitors were used. Due to their orientation, the glazing area required was more than the south-facing monitors, thus this design costs more. On the energy side, in our climate, there was the concern of heat losses through the north glazing, leading to an increase in building energy use. North monitor design was maximized by using the back-side (south-facing) to mount solar collectors, wherever applicable. This combined approach helped cut down on overall costs, while providing adequate daylighting [17].

3.8. Daylighting systems

Daylight is defined as ‘‘the combination of the diffused light from the sky and sunlight’’. A daylighting system is a device located near or in the openings of building envelope, whose primary function is to redirect a significant part of the incoming natural light flux to improve interior lighting conditions. There are two simple daylighting systems, namely, side-lighting and top-lighting. Side-lighting, which is more commonly observed, is simply a window opening. Top-lighting is an opening in the ceiling or roof element of the building [2].

3.8.1. Using light shelves

The light shelf is a classic daylighting system. This system has been designed to prevent light reflection, shadowing and direct rays from the sky. The light shelf is usually placed horizontally to the interior or exterior of the window front. The light

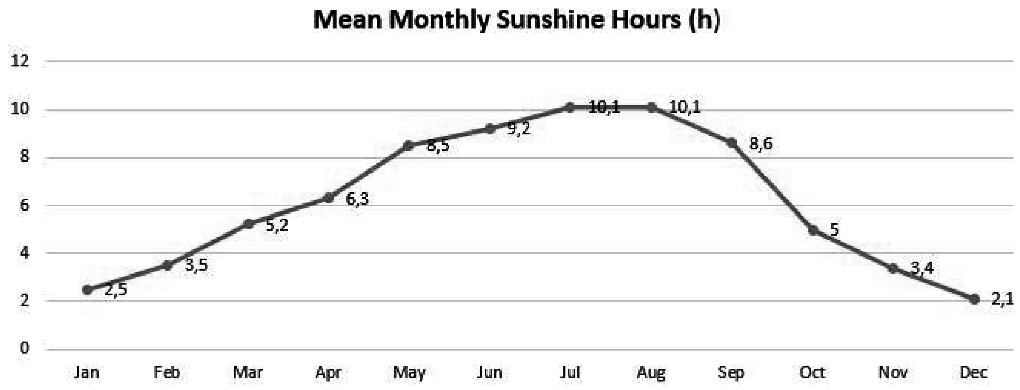

Fig 2. Mean monthly sunshine hours of Kirklareli city

shelves divide the window as the scenery part is below and upper part points upwards (Fig. 1-a). Their placements are selected according to the direction of window, position of room, ceiling height and the eyes level of people in room. They can be applied to deep places to the south direction in the north hemisphere. They do not work in the east and west directions and in cloudy weather [16,18].

3.8.2. The use of louvers and blinds

The blind system is a classic daylighting system to prevent shining and daylighting and enable shadowing. They consist of multiple horizontal and vertical slats (Fig. 1-b). The exterior blinds are usually made of stainless steel, anodize, painted aluminum or PVC which is low costing and highly resistant. The slats can be smooth or curved. The size of slats can differ according o the size of blind [16,18].

3.8.3. The use of a laser cut panel

The laser cut panel is a thin transparent acrylic panel with parallel cuts made using a laser cutting machine (Fig. 1-c). A LCP makes an array of cuts at an angle perpendicular to the surface. Each surface of laser cut turns acts like small mirrors that deflect the light passing through the panel. The panels direct the light upwards. These cuts are usually made through the panel because this method requires less control of the cutting speed and laser power than other methods. Therefore, the panel should have a 10- to 20-mm-long solid part to support the cut sections. The acrylic panel is usually fixed between two glass panes to form a double glazed window. They are placed above the eye level to prevent shining [18].

3.8.4. The use of light guiding shade

The light guiding shade is an exterior shadowing system that direct sky and sun light to the ceiling. The light guiding shade consists of distributive glass space and two reflectors made for directing the light sprawling from building space with angles in the significant angular range (Fig 1-d). The light guiding shades are more complex that traditional shadowing systems. Highly reflectant materials must be used in interior areas. The light guiding shade systems are placed on the upper half of the window or upper one-third of part [16,18].

3.8.5. The use of light guiding glass

These are made of concave acrylic material placed vertically between two panes of glass (Fig. 1-e). They reflect the daylight coming in directed or direct from all angles to the ceiling. The other important part of the system is the ceiling that conveys the directed light to the work space by reflecting it. This system is placed to eye level to prevent shining and other visual effects [16,18].

3.8.6. The use of an anidolic ceiling

The first aim of anidolic ceiling system is to supply enough daylight to rooms in cloudy weather condition. The anidolic ceiling consists of daylight collecting optics attached to a light canal on the hanged ceiling (Fig. 1-f). The system is designed to be placed on the window. Since the system is designed to collect the light sprawling from the sky, it can be used in every latitude. On sunny days, the shining that stems from the sun light affecting directly and the excessive heat can be prevented by the protecting entrance glass [16,18].

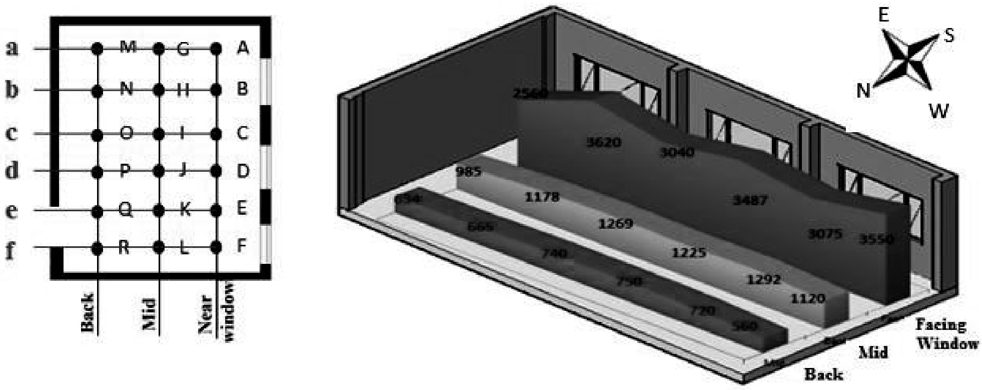

Fig. 3. The daylight chart for the south facing classroom (TEF-201)

4. THE COMPARATIVE ASSESMENT OF DAYLIGHTING PERFORMANCES OF CLASSROOMS

A number of daylight simulation techniques, have been developed over the past 50 years, making use of simulated or artificial skies and building models. These simulation techniques also have the advantage of allowing for unique buildings shapes and room configurations [19]. One of the most important daylighting simulation programs is Velux Daylight Visualiar. In this study, the classrooms in Kavakli and Kayali Campuses of Kirklareli University are simulated using Velux Daylight Visualiar.

Illumination performances of classrooms were assessed by the daylighting measurements made. Kirklareli is located in the northwest of Turkey, at 41° 44’ N latitude and 27° 13’ E longitude. Fig. 2 shows the mean monthly sunshine hours of Kirklareli city. In March, when the experimental measurements were made, Kirklareli has 5.2 hours of sunshine time.

4.1. Daylighting measurements of classrooms

The layout of the existing classrooms of Kirklareli University in Kayali and Kavakli Campus is introduced in the sense of the general daylighting performance.

A classroom in the south and north direction on Kavakli Campus and a classroom on Kayali Campus have been chosen. The schematics and measurements of the chosen classrooms have been taken and the window size and position have been placed in the drawing program. The measurement points at 2 meters intervals have been drawn according to the middle axle of the classroom plan and measurements have been carried out with a lux meter at the 85 cm work height. The measurements have been put into graphics using Excel.

The classroom seen in Fig. 3 is located on the second floor of the Technical Education Faculty building and faces south. The classroom has three windows. Each windows has two double pane glass with the following characteristics: external and internal glass is 4 mm thick, the air filled insulation gap is 12 mm thick.

Illuminance measurements have been taken between 12:30–12:50 pm on the 21st March. As can be seen from the Fig 3, the illuminance in regions close to the window is excessively high in the measurements that have been taken when the sun directly affects the interior of the classroom. Since the glaring and reflecting will increase depending on the daylighting, the sunlight must be prevented. Therefore, the curtains are used in the classrooms. However, the curtains entirely block the daylight. Instead of this a simple blind system can be used.

The classroom seen in Fig. 4 is also located on the second floor of Technical Education Faculty building, but is north facing. The classroom has four windows. Each windows has two double panes of glass with the following characteristics: external and internal glass is 4 mm thick, the air filled insulation gap is 12 mm thick. According to the measurements taken between 12:50–13:20 pm in the north-facing classroom in the same building the illuminance values are higher, but it is not at a disturbing level.

The classes in Kavakli Technical Education Faculty buildings are rectangular in size and positioned in parallel to the facade of the building. The windows are on the long side of the classroom. Therefore, the required window intervals can be easily obtained for natural illumination of the classroom.

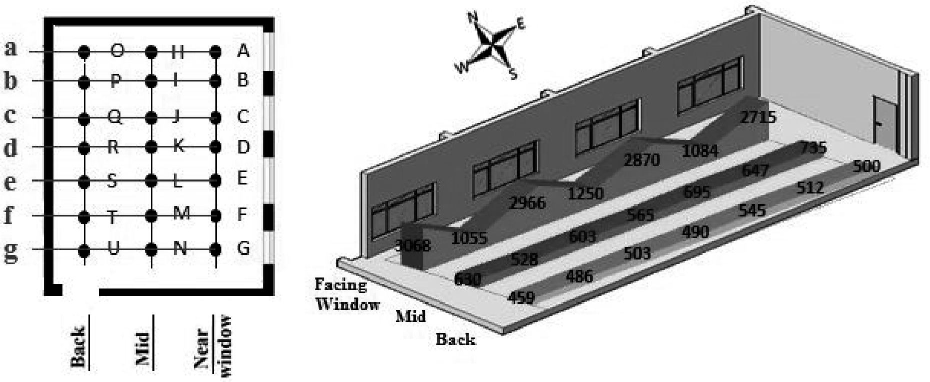

Fig. 4. Daylight chart for the north facing classroom (TEF-208)

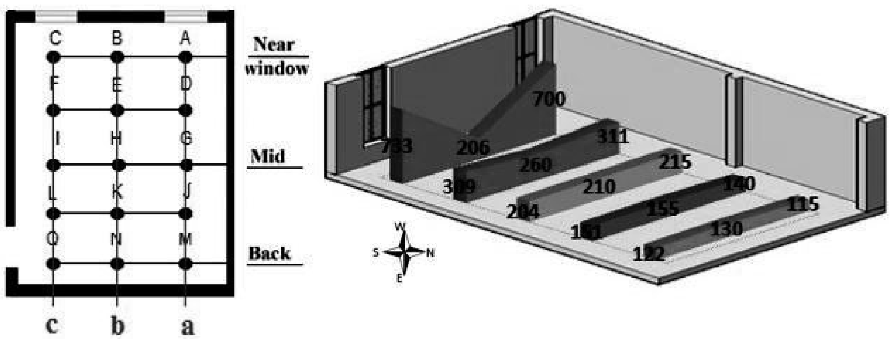

Fig. 5. Daylight chart for the south-west facing classroom (Central classroom building, Z-42)

The last measurement has been taken from an existing classroom on the ground floor of the newly built building in Kayali Campus of Kirklareli University between 11:30–12:00 pm on the 21st March. The classroom is also rectangular in size, but the layout of this classroom is different. The windows are on short side of the classroom. So, a deeper distance has been created and narrow and long windows have been designed.

According to the measurements, it can be seen that the illuminance is insufficient in all parts of the room except from the windowsills. The main reason for this is that the entire window area is insufficient. Two windows (0.90x3.60 m) have 6.28 cm^2 areas and a lower 10 percentage rate than the total area of the class. Although the windows have 3.60 meter height, they are insufficient because of their narrowness and number. It is necessary to increase the windows that prevent glaring and reflecting since they face in north direction. The classes in Kayali center have been placed vertically to the front. In order to reach the wanted illuminance level, the necessary window area can be supplied by dividing the entire front area with window interval.

4.2. Daylighting simulation results for the classrooms

In this study the natural lighting simulation of an existing classroom in Kayali Campus and two classrooms in a building belonging to the Technical Educational Faculty in Kavakli Campus of Kirklareli University has been carried out usuing the Velux Daylight Visualizer program. The results of simulation are given below.

As can be seen from Figs. 6–7, the illuminance in regions close to the window is high the same as in the measurements. In Fig. 8, the classroom's illuminance level is insufficient at all points apart from the windowsills. The main reason of this is that the whole window area is insufficient. Illuminances shown in the following Figs are in foot-candle.

5. RESULTS AND DISCUSSIONS

The results of simulation made on the natural lighting in the educational institutions support the literature information presented above. The illuminance levels of the classerooms facing in the south direction in Kavakli Campus is higher

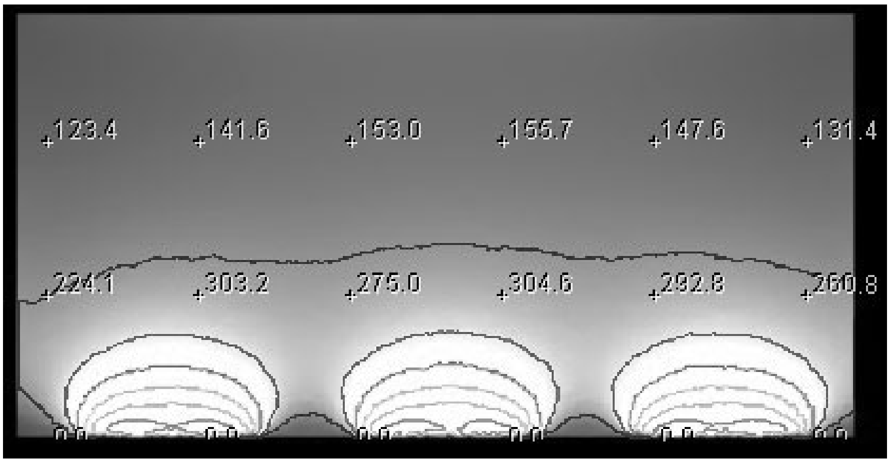

Fig. 6. The lighting simulation of the TEF-201 classroom in Kavakli Campus

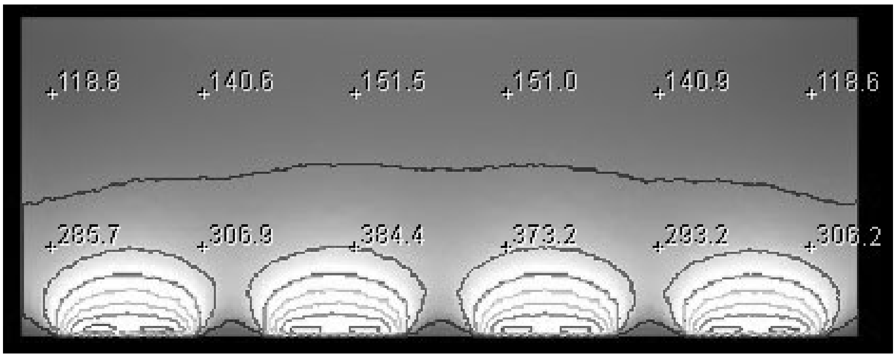

Fig. 7. The lighting simulation of the TEF-208 classroom in Kavakli Campus

depending on window interval, but it leads to luminance and glare. Therefore, if a uniform illumination is desired, the designs that don't directly take the daylight into the space must be made. The interval in the upper limit must be done for the lighting if it is possible. If this does not work, light shelves, lightpipes and lightwells should be preferred.

The window intervals and sizes in the class existing in Kayali Campus are insufficient for natural lighting. The window intervals must be horizontal instead of vertical, by in way much more daylight can be benefited from by using a light shelf. When the simulation results of the classerooms in both buildings are evaluated, it becomes clear that the buildings were designed before the natural lighting design for classroom usage had been considered.

6. CONCLUSIONS

Although the daylighting level of spaces differs in terms of directions, the measurements taken from the north direction has displayed that if a sufficient enough window interval is used, the wanted illuminance in the spaces facing north can be obtained. The minimum net glazed (window) area should not be less than 1/3 or 1/5 of the floor area of the room served [20]. Therefore, in Kavakli Campus classrooms, the floor area ratio of windows are respectively 1/5,54 and 1/5,58. But, in Kayali Campus classroom, the floor area ratio of window is 1/10,54. In this classroom, sufficient illuminance can not be obtained with the existing windows and building orientation, as has been observed by the results of the simulation and measurement. So, in order to increase the illuminance level, a suitable daylighting system (light shelf, anidolic, ceiling etc.) must be chosen. The light pipes must be chosen for classes near the roof. The appropriate selection of wall colour, ceiling and ground covering will be helpful to obtain sufficient illuminance levels.

As it is known, the use of daylight helps energy saving. Furthermore, it contributes to the success of students by affecting their psychology in a positive way. Therefore, when desgning educational buildings, in cooperation with architects and installation engineers, buildings that will supply

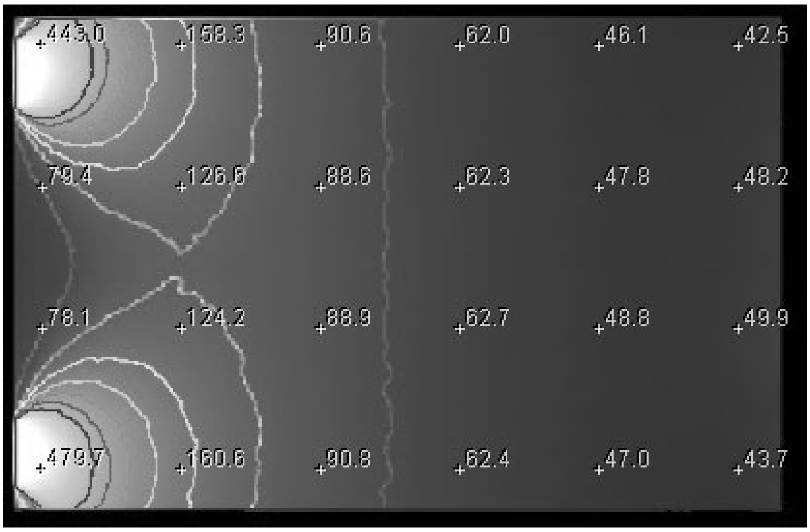

Fig 8. The lighting simulation of the Z-42 classroom in Kayali Campus

more efficient work places must be constructed with an interdisciplinary effort from the beginning and to the end of the project.

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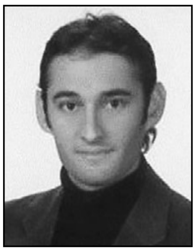

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