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New comfort evaluation criteria: application on movie-theatre design

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Abstract

Purpose:
Authors have developed a new comfort evaluation criterion that improves the International Standard Evaluation criteria like OCRA, RULA, etc. adding new information coming from bio-mechanical parameters opportunely weighted. Authors wants to show how this method, originally developed for Industrial application, can be easily applied in most of postural comfort evaluations and how it can be used, for example, in movie-theatres' design.

Method:
Developed criterion has been applied in order to evaluate not only the seat-comfort (the viewer's comfort when seated) but also the viewer's comfort during the screening of a movie; viewer postural comfort is heavily affected by the relative position (distance and angle) between the seat and the big-screen: developed method can take that into account!

Result:
Output of this work is a Design Method for mapping the movie theatre's seats taking into account the postural comfort matter.

Discussion & Conclusion:
This work allows to show how the developed method is easy to use and how important the preventive ergonomic evaluation is in all fields of engineering design.

1 Introduction

Design activity of a movie-theatre, like the design of each kind of public-entertainment facility, shows a lot of troubles regarding facility safety, dimensioning of way-out systems in case of fire/earthquake, fire prevention systems, protection facilities for acoustic control and, last but not least, comfort and ergonomics issues. Comfort factors can be classified in two classes: postural ones and visual ones.

Experience and common sense give us several information about comfort matter in movie-theatres enjoying. It seems easy to answer to questions like: "Is the seat comfortable?" – "Have you a good sight of the movie?" Everyone can answer to those questions but, in design phase, movie theatre designers need to use an objective tool to evaluate the visual and postural comfort level for each seat.

In order to take into account the postural comfort level, we've developed a new method to evaluate human comfort [16]; our comfort evaluation criteria starts from human ergonomic analysis and extends ISO 11228 [6] analysis for comfort evaluation. The method is based on the analysis of human body positions in which, using ISO 11228 criterion, we reach a good ergonomic level but not a good level of comfort. This method has been explained in the fourth paragraph.

The final purpose of our study is a new evaluation method of postural/visual comfort [1] [2] for each facility that provides a high number of seats for public-entertainment (like movie-theatres).

For that kind of facilities we can state some considerations:

- Each of us, when going to movie-theatre, wants to be seated not too far from or too close to the screen in order to not have sights problems.
- Each of us prefers to be seated in the centre of the cinema-hall in order to not be forced to rotate the head for a better viewing and hearing.

Using these easy criteria for choosing the seat, it seems easy to identify the worst seats' locations and avoid them.

We imagine that the worst seats are the first row's ones and the extremely side ones; in those seats neck and shoulders need to rotate too much in order to allow the eyes to have a good sight [3] [4]. At the same time central first-row seats' occupants have a very narrow visual cone because of their relative position towards screen height; this position forces the viewer to move continuously his head in order to focus not only the screen centre but also other parts of the screen for following movies' scenes.

2 Test-case

Our comfort evaluation method has been applied to the comfort analysis of C-hall of a new movie-theatre in Castellamare di Stabia (Naples). This hall has a capacity of 252 seats. The following geometrical data are needed to perform comfort analysis:

- Distance between two consecutive rows;
- Distance between two adjoining armchairs;
- Distance between each armchair and the geometric centre of the screen;
- Dimensions and shape of each armchair (supposed to be equal each others);
- Height, Width and position of the screen.

In the following figures you can see two design sheets of the C-hall with several dimensions reported.

As you can see, the C-Hall of this movie-theatre is not symmetric.

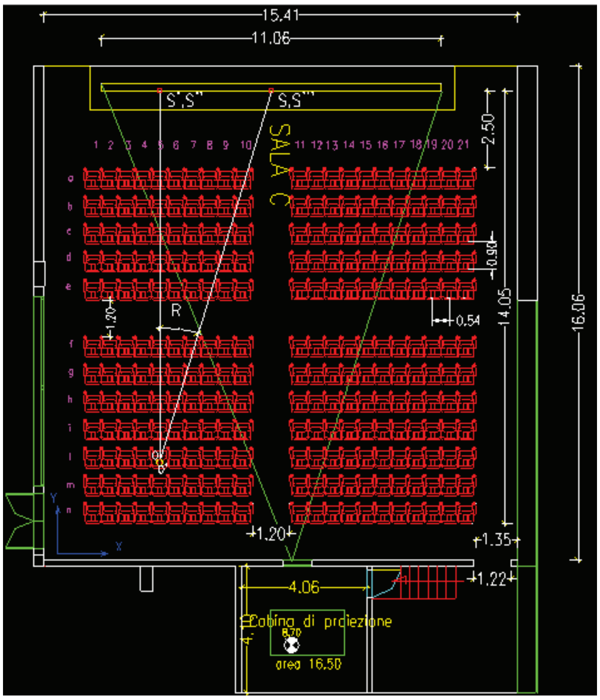

Fig. 1 Horizontal section at the height of projection cabin

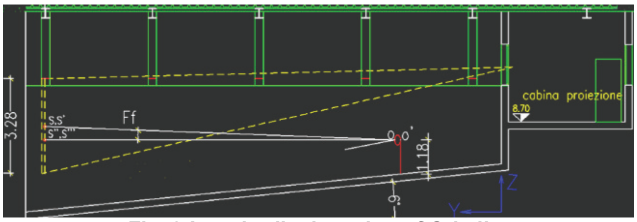

Fig. 2 Longitudinal section of C-hall.

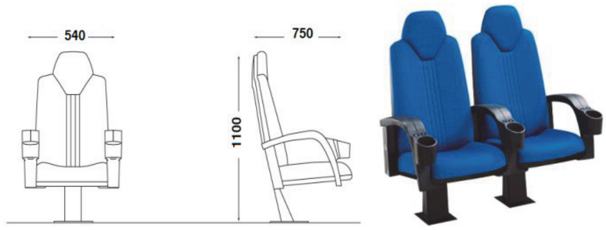

Fig. 3 "Evolutionseat-1" armchair model.

3 Identification of main parameters

For designing the theatre and evaluating the seats' comfort we will use two different 2-dimensional Cartesian coordinate systems. Let's fix the Cartesian axes' origin of the system XY in the lowest left corner of the movie-theatre (that, as you can imagine, has a slight slope – see fig.1) and the Cartesian axes' origin of the system YZ in the lowest right part of the selected longitudinal section; in figg. 1 and 2 both systems are highlighted in blue color. XY and YZ systems have been used like reference planes for determining several geometric parameters.

Geometric parameters are used for comfort analysis because they allow us to calculate lateral neck-rotation angle and frontal neck-flexion value for each seated movie-watcher [3] [4] [10]. In our comfort evaluation method it's possible to connect each angle's value (both for flexion and for rotation) with a comfort index.

The centre of the theatre screen will be considered like the point on which the eyes of each watcher set his sight on. When a seat-occupant sets his sight on the screen he is naturally able to capture an image with a field of view of about 200°; only a little part of this "captured image" is brought into focus and can be followed without problems: this part is generally defined as optical cone and often is too small to allow to an occupant of the first row to bring into focus the entire screen! Our study doesn't take into account the head/eye movement, due to scene following action, that all screen-closer watchers are forced to do.

Screen and seats have been positioned in the theatre hall like the external designers asked. In figures 1,2 you can see the results of the method used for numbering all armchairs (in magenta color): the chairs closer to screen are numbered with row "a" while the more distant are numbered with row "n"; each row is numbered from 1 to 21, from the left to the right.

F11xy states for the armchair number 11 of the row "F" whose coordinates are brought on XY Plane.

For each occupant we used his H-Point for configuring his position on the chair; because of the particular shape of the seat and of the splat, we fix the H-point of the occupant (represented using a manikin) in the lowest point of the seat at a Z-Distance from the floor equal to mm.360,00. The software DELMIA^{tm} has been used to settle the manikin on the armchair; the used manikin is representative of the anthropometric model of the 50th percentile European male (French male).

In the first postural analysis only the following parameters have been taken into account [2] [13] [14]:

- Distance between the point of view (in the middle of the eyes) and the H-Point: mm.820,00;
- Distance between the higher point of the head and the H-Point: mm.932,00;
- Distance between the acromion and the H-Point: mm.620,00;

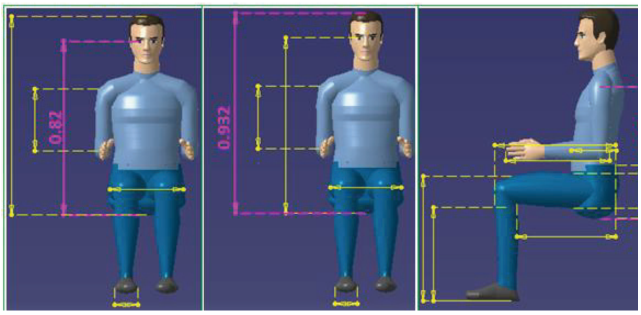

Fig. 4 Measures and geometric Characteristics of human model

Using these parameters, all distances (in meters) and angles (rotation/frontal bending in degree) have been calculated for each seat in the hall, by defining the segment that connect the geometric centre of the screen “S” with the three defined points (top of the head, middle of eyes, H-Point).

4 Comfort Evaluation method

After geometrical positioning, each chair in the hall can be identified by a couple of values referred to the occupant neck: lateral rotation angle and frontal bending value [1] [2] [15]; these two values are needed to calculate the comfort index of the armchair when occupant is viewing a movie.

Needed values have been calculated using our new comfort evaluation criterion [16]. This criterion is based on the extension of ISO 11228 [6] in the Articular Motion Range in which human body reaches a good level of ergonomic values but it is not in comfort. The method is based on the elaboration of a wide data set coming from experimental tests.

In [16] we’ve described the tests used to evaluate ergonomic values and comfort values of several human body articular joints around their natural rest position; rest position has been taken as the maximum comfort value’s position for each joint and several tests have been made to evaluate comfort curves for position around rest position (deviation expressed generally in degree).

Human neck is one of the joints that has been studied in our experimental work.

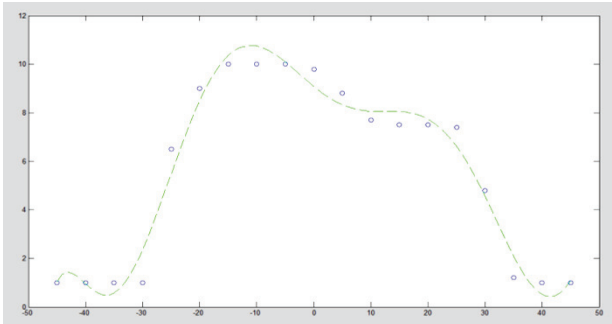

Fig. 5 Frontal flexion approximated curve

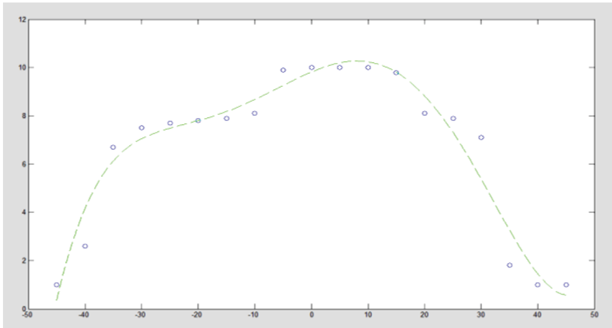

Fig. 6 Lateral rotation approximated curve.

In the first time the neck has been tested in lateral rotation and in frontal flexion, in independently mode; this testing phase allowed us to elaborate the mean comfort curves around the rest position (mean made among more than one hundred test-case different each-other). Those curves are represented in figures 5 and 6.

In our real application two different and independent comfort indexes, each for one of those angles, have been calculated and then they have been coupled using an ergonomic criterion.

Differently from what one can imagine, It happens that comfort indexes are not equal each other when the angle has the same value but opposite sign. It’s demonstrated that different values of comfort are felt by humans when turning the neck on the right or on the left side.

5 Results

In order to make the results’ analysis easy to be understood we’ve shown it using 3D graphs

Dealing with comfort and discomfort seems to be useless because those two concepts are complementary each other.

Our first comfort evaluation method [16] gave a value to “postural and visual comfort”; when past results have been shown to designers, they always ask to us to see discomfort iso-curves (designers need to know where the seats have not to be placed!!!), so we’ve presented our results using both kind of curves.

In fig. 7 we’ve defined a bi-dimensional domain whose axes represent columns (colonne) and rows (file) in the theatre hall. Columns are numbered from n.1 to n.21 while rows are numbered form row A to row N. Z-Axis represents the comfort value due to frontal-flexion of the neck; its range varies to from 0 to 10 (the best comfort evaluation). The blue “S” letter stands for screen centre position. The graph in fig.7 shows that central seats suffer for a lower comfort level; comfort value in the first rows is between 6 and 6.5. When putting the viewer away from screen, his comfort value grows sharply in the first rows, then linearly in the central rows and, in the last rows, becomes almost constant. The first rows' big gradient is due to the neck model used in our evaluation method: this model takes into account the real flexibility of the human neck so that for higher flexion angle the neck cannot flex itself and a viewer needs to flex chest or shoulders.

In the back-central part of the hall the comfort value is almost constant because neck flexion is in a good comfort range and finally last rows reach the higher value of comfort for frontal flexion. Obtained results seem to match perfectly the experimental results coming from each of us experience: if you don't have shortsightedness problems you always prefer to buy tickets for last rows seats because your neck frontal flexion will be minimized!

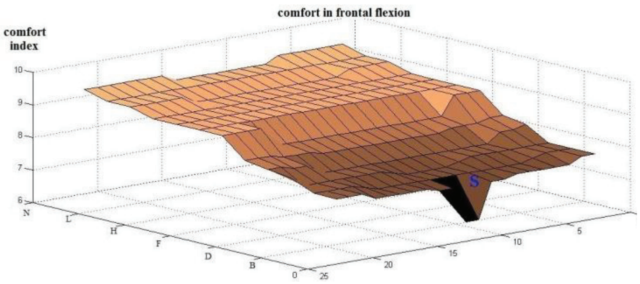

Fig. 7 Frontal Flexion Comfort evaluation represented by a 3D Surface.

In fig. 8 we show the 3D surface representing the comfort evaluation for neck lateral rotation. We clearly see that, for each row, comfort value decreases when going from central seats to side ones. But, while in the last rows the horizontal decrease gradient is very low, in the first row this decrease is very marked.

It's very important to highlight that, as waited, values distribution along seats of a single row is not symmetric towards screen-centre. In fact, our evaluation method [16] follows the experimental evidence that suggest a different comfort values for the same rotation in the opposite side (a 15° left-rotation has a different comfort value towards a 15° right rotation). This behavior causes the best comfort values in the last row, for seats numbered from 6 to 11.

Going from last row to the central ones, side seats' comfort value begins to decrease because the distance between viewer and screen-centre diminishes and, consequently, the neck rotation angle increases. This behavior is as more evident as more the viewer stays close to the screen.

Analyzing fig.8 you can see that several first row seats in left and right sides have a comfort value equal to 0. It happens because our evaluation method, as told before, takes into account the real human neck behavior: if a human neck overrides 45° lateral rotation, it can causes itself several damages to vertebral arteries [11] [12]; in our method this angle (45°) represents the maximum allowed rotation angle over which the comfort is equal to 0 because a viewer is forced to rotate shoulders and chest.

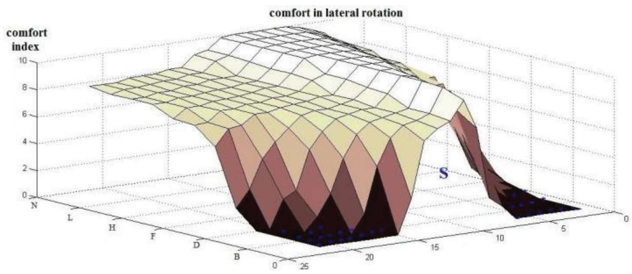

Fig. 8 Lateral rotation Comfort evaluation represented by a 3D Surface.

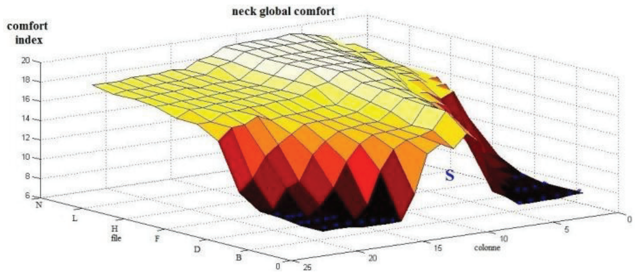

Fig. 9 Global comfort evaluation represented by a 3D Surface.

In fig. 9 we show the comfort final value function; it has been obtained adding results shown in fig. 7 and 8, in order to discriminate the weight of each factor: let's analyze them! As expected the most comfortably seats are the ones numbered from 6 to 10 in the last row because in those seats lateral rotation and frontal flexion are minimized. If we go away from the last row versus central row, also in side seat, we can observe that there's no high decrease of the comfort: it can be explained with the compensation of lateral and frontal angles (if the viewer moves himself in the last rows from the centre to the side, the lateral rotation increases but, because of increasing of distance, the frontal flexion decreases) so that the rows between the last and the central show circa the same comfort values.

Let's observe that the frontal flexion increase, going away from central seat to side seat, is more evident in the close-screen seats than in the others.

The common sense of feel suggest us that the most uncomfortably seats are the side seats in the first rows. Our study demonstrates that!

In fig. 10, such as described before, discomfort surfaces are shown for frontal flexion, lateral rotation and for the whole comfort value.

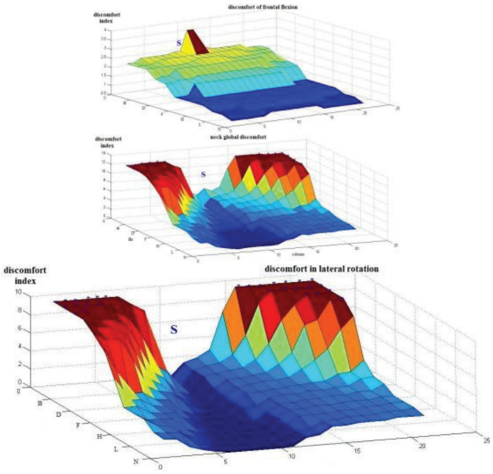

Fig. 10 Discomfort representations for neck in a movie theatre.

6 Conclusion

As shown in results before reported, our comfort evaluation criterion allows to determine several indexes, easy to be used, by which comfort analyses for each facility that provides a high number of seat for public – entertainment (like movie-theatres) can be fulfilled. Our study demonstrates how the common sense of understanding and feel the comfort, when seated in a movie theatre, is comparable with our results: obtained results perfectly match the experimental ones coming from common sense of judge when buying a ticket to go to movie-theatre!

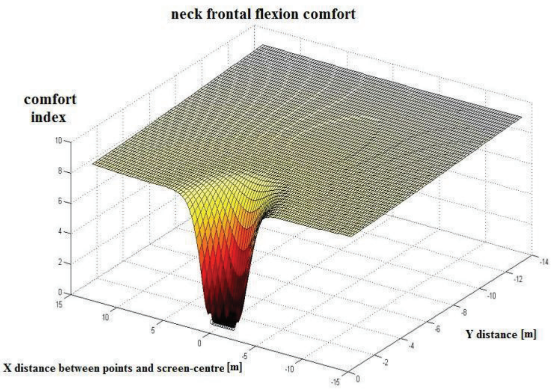

Fig. 11 Function representation for comfort variation due to neck frontal flexion.

Another proof of what said can be obtained by building a mathematical function on the spatial domain defined by the theatre hall. In this domain comfort curves have been represented (fig. 11 to 13) like function of X-Y distance between points and screen-centre. The analyzed range for neck frontal flexion and lateral rotation is limited to 0-15 meters values and used function for interpolating data is a parametric cubic surface.

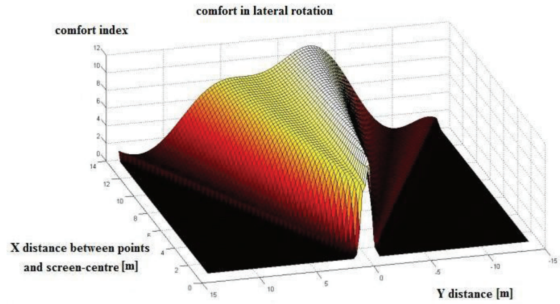

Fig. 12 Function representation for comfort variation due to neck lateral rotation.

Using the same criteria we can obtain the global comfort function whose values are expressed in function of distance from the screen.

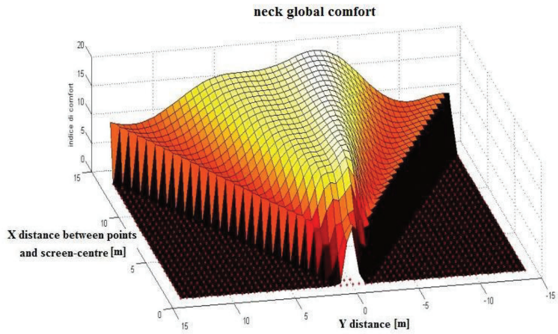

Fig. 13 Function representation for global comfort variation.

Last shown results are the Iso-Comfort curves, in figg. 14, 15 and 16. These curves allow to identify seats for which a defined comfort level is fulfilled. The used unit of measure can vary in a range from value 0 to value 20, obtained like simple sum of two indexes' values described in this paper.

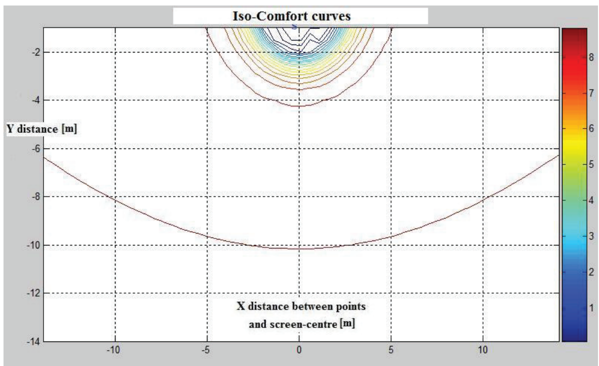

Fig. 14 Iso-comfort Curves for frontal flexion.

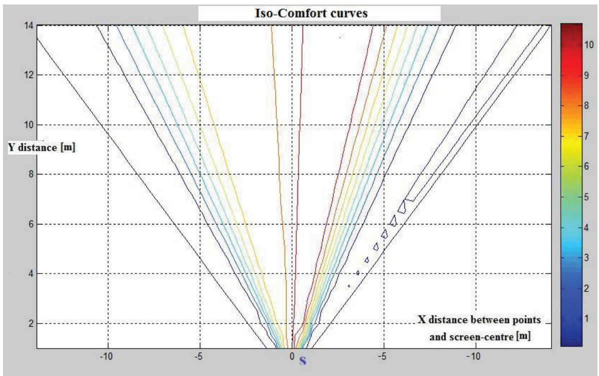

Fig. 15 Iso-comfort Curves for lateral rotation.

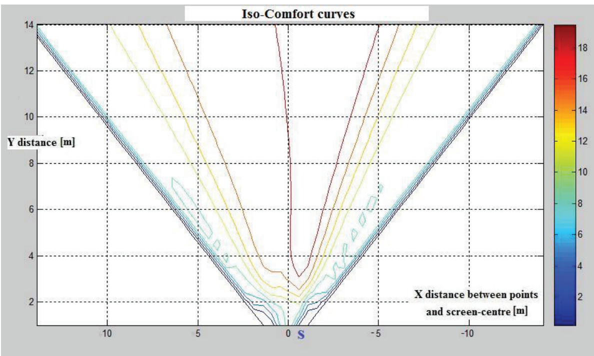

Fig. 16 Iso-comfort Curves for global comfort value.

Iso-comfort curves give more accurate information about discomfort due to frontal flexion and lateral rotation of the neck. It's interesting to observe that the shape of the iso-comfort curves replicates the shape of growing occupied seats during the ticket buying.

Our method can manage a high level of detail in comparing postures each others: the clearest example of this level of detail is the possibility to have different comfort values for two adjoining armchair. In our test-case the postural parameters used for evaluating the comfort have been chosen in subjective way and their number has been reduced in order to easily verify the capabilities and the affordability of our method. In real comfort evaluation a lot of parameters have to be taken into account. These parameters involve both postural and visual comfort and have to take into account several other parameters like interaction between deformable seat and human legs or asymmetry in perception of comfort during neck/shoulder rotation (due to mores and environments factors). More studies can be faced and the whole comfort can be evaluated always using our criterion.

Finally we can say that the developed method allows to make objective comfort-analyses, giving a few indexes very easy to use in graphic post processing and numerical/statistical elaborations. Obtainable results are comparable with common experience.

Acknowledgement

Studies are based on experimental tests made on over one hundred people in Ergonomics and Virtual Reality Laboratory in University of Salerno (Italy). The movie theater hall has been re-designed by a young engineer (eng. Fondacaro – [17]) on the basis of the authors' study in order to achieve the best distribution of the global comfort index among all over the seats in the hall. In the following figures are shown three different layout solutions for improving viewer comfort.

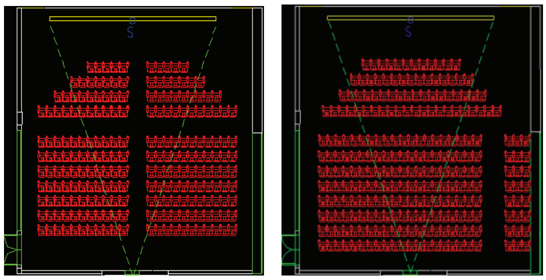

Fig. 17 New layouts: with a reduced number of seats (left) and with the same seats (right).

The first and the second layout are designed in the same C-hall area (Fig. 19). The third one (Fig. 20) is a new design proposal for the best whole comfort.

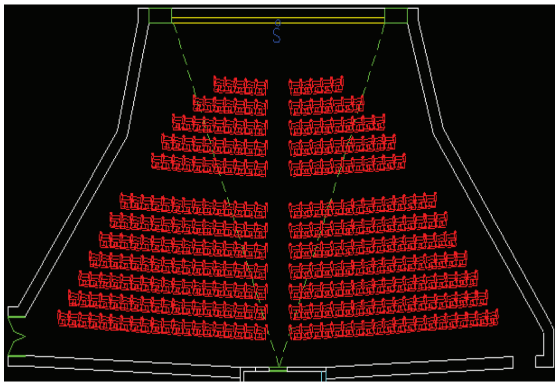

Fig. 18 A new design proposal for improving viewers' comfort.

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