Palestine Polytechnic University

Deanship of Graduate Studies and Scientific Research

Master of Architecture – Sustainable Design

Healing Environment in the Intensive Care Units: enhancing daylight and access to view, cases from Palestine

by

Deema Ishaq Amleh

Supervisor

Dr. Abdelrahman Halawani

Thesis submitted in partial fulfillment of requirements of the degree

Master of Architecture- Sustainable Design

September, 2020

The undersigned hereby certify that they have read, examined and recommended to the Deanship of Graduate Studies and Scientific Research at Palestine Polytechnic University:

Healing environment in the intensive care units: enhancing daylight and access to view, cases from Palestine

Deema Ishaq Amleh

in partial fulfillment of the requirements for the degree of Master in Sustainable Design

Graduate Advisory Committee:

Prof./Dr. ………………………………,…………………………..

(Supervisor), University (typed)

Signature:—————————————— Date:————————————

Prof./ Dr. ………………………………, …………………………………..

(Co-supervisor), University (typed)

Signature:—————————————— Date:————————————

Prof./Dr………………………………………,……………………..

(Internal committee member), University (typed).

Signature:—————————————— Date:————————————

Prof./Dr. …………………………………………,……………………..

(External committee member), University (typed).

Signature:—————————————— Date:————————————

Thesis Approved by:

Name: ____

Dean of Graduate Studies & Scientific Research

Palestine Polytechnic University

Signature:……………...…………………

Date:…..……………...…………………

Healing environment in the intensive care units: enhancing daylight and access to view, cases from Palestine

Deema Ishaq Amleh

ABSTRACT

Daylight and access to outside views are key factors to improve the healing environment for patients in the intensive care unit (ICU), which decreases the incidence of delirium. This is essential as well to provide appropriate working conditions for healthcare providers. Besides the geographic location, daylight in any space is mainly affected by five parameters: window orientation, window level, window to wall ratio, light reflectance value of the inner surfaces of the walls and the used shading device. This study aims to assess the conditions of the ICUs in the Palestinian hospitals in terms of providing daylight and access to view, by analyzing the ICUs' plans and making field visits to take observations and daylight measurements. Furthermore, interviews were conducted with the medical staff to describe their satisfaction, observation and patients' complaints. The study also extends to optimize the parameters affecting daylight to achieve the optimal daylighting while minimizing the heating and cooling loads without restricting patients' access to view, through conducting a multi-objective optimization using DesignBuilder simulation tool, and to use the results to modify the current designs of the studied ICUs. The study found that the ICU designs in Palestine do not deliver adequate daylight and access to view for patients. The results of the optimization phase show differences in the optimum values of the window to wall ratio, window level and the shading devices specifications according to the type of the patient area and the orientation scenario. While it was found that the south is the optimum orientation and 0.9 is the optimum light reflectance value of the indoor surfaces. Furthermore, the study found that there is a high potential for enhancement of the current ICUs that have shallow-plan layouts using the optimization results.

بيئة الشفاء في وحدة العناية المكثفة: تحسين الإضاءة الطبيعية والتواصل مع البيئة الخارجية, حالات دراسية من فلسطين

ديما إسحق العملة

المستخلص

يلعب تصميم وحدات العناية المكثفة دوراً كبيراً في جودة الخدمات الصحية المقدمة فيها، حيث أن تصميم البيئة الداخلية الذي يوفر الإضاءة الطبيعية ويسهل رؤية المناظر الخارجية من أهم العوامل التي من شأنها تحسين بيئة الشفاء للمرضى، والتي تقلل من احتمالية إصابتهم بالهذيان المصاحب للمكوث في وحدة العناية المكثفة. كما أن لها دوراً هاماً في توفير بيئة عمل مناسبة لمقدمي الرعاية الصحية. لذلك يتوجب عند التصميم استغلال الإضاءة الطبيعية بالشكل الأمثل وتمكين المرضى من التواصل مع البيئة الخارجية، حيث وجد أن هذه العوامل تقلل من الاصابة بالهذيان. إضافة إلى الموقع الجغرافي، يعتمد مقدار وتوزيع الاضاءة الطبيعية في الفراغ بشكل رئيسي على توجيه النافذة، وارتفاع مستواها، ومساحتها بالنسبة للجدار، بالاضافة إلى عمق ونوع نظام التظليل المستخدم، ومعامل الانعكاس للاسطح الداخلية للفراغ. تهدف هذه الدراسة إلى تحليل وضع وحدات العناية المكثفة في المستشفيات في فلسطين من حيث الاضاءة الطبيعية وتواصل المرضى بصرياً مع البيئة الخارجية. كما تهدف الدراسة أيضاً إلى تحديد القيم المثلى للعوامل المؤثرة في الإضاءة الطبيعية باستخدام برنامج المحاكاة (DesignBuilder) من حيث توفير أفضل إضاءة وأقل طاقة ممكنتان، بدون إعاقة الرؤية عبر النافذة. واستخدام هذه القيم لتحسين وضع وحدات العناية المكثفة في فلسطين في ضوء تطبيق المعايير التصميمية المطلوبة. وجدت الدراسة أن تصميم وحدات العناية المكثفة في فلسطين لا توفر الإضاءة الكافية والتواصل مع البيئة الخارجية للمرضى. كما وجدت أن القيم المثلى للعوامل المؤثرة في الإضاءة الطبيعية تختلف وفقاً لتغير نوع المنطقة المخصصة للمرضى وتغير توجيه النافذة. بينما يعد اتجاه الجنوب أفضل توجيه، وتعد القيمة 0.9 أفضل قيمة لانعكاس الاسطح الداخلية من حيث الاضاءة. باللإضافة إلى ذلك، فقد وجد أن هناك احتمالية جيدة جداً لتحسين وحدات العناية المكثفة الحالية التي لها شكل ضحل (قليل العمق) باستخدام القيم المثلى التي نتجت من الدراسة.

DECLARATION

I declare that the Master Thesis entitled" Healing environment in the intensive care units: enhancing daylight and access to view, cases from Palestine" is my own original work, and herby certify that unless stated, all work contained within this thesis is my own independent research and has not been submitted for the award of any other degree at any institution, except where due acknowledgement is made in the text.

Deema Ishaq Amleh

Signature: Date:

DEDICATION

This work is dedicated to my family who provided all kinds of supports and encouragement.

To my supervisor, teachers and classmates who shared their advice and help to accomplish this study.

And finally, in the hope that this work will help them improve the standards of hospitals, this is dedicated to the Palestinian Ministry of Health.

ACKNOWLEDGEMENTS

I would like to express my profound gratitude to everyone who helped me accomplish this work, specially, the ICU crews and the maintenance engineers of Alahli-Hospital, Alia Governmental Hospital, Palestine Medical Complex, Istishari Arab Hospital and An-Najah National University Hospital for their generosity in giving information and their cooperation when taking measurements and observations in their work environment.

I would also like to acknowledge the License & Accreditation Unit of the Palestinian Ministry of health for their help in hospitals' classification.

Table of Contents

DECLARATION v
DEDICATION vi
ACKNOWLEDGEMENTS vii
List of Figures xii
List of Tables xvi
Chapter 1 - INTRODUCTION 1
1. Introduction 1
1.2. Scope of the Study 4
1.3. Problem Statement 4
1.3. Research Objectives 6
1.4. Research Structure 7
Chapter 2 - HEALING ENVIRONMENTS 8
2.1. Preface 8
2.2. Healing Environments 8
2.3. Daylight and Human Health 9
2.4. Access to View and Human Health 10
2.5. Conclusion 11
Chapter 3 - INTENSIVE CARE UNIT (ICU) 12
3.1. Preface 12
3.2. ICU Design 12
3.2.1. ICU Sizing 14
3.2.2. Functional Design of ICU 14
3.3. Lighting Design Standards of ICU 18
3.4. The Impact of Daylight and Access to View on ICU Patients and Staff 18
3.5. Conclusion 21
Chapter 4 - NATURAL LIGHT 22
4.1. Preface 22
4.2. Daylight Measurement 22
4.3. Parameters Affecting Daylight in Healthcare Rooms 23

4.4. Daylight, Thermal Comfort and Energy Consumption 24
4.5. Visual Comfort and Glare 25
4.6. Conclusion 26
Chapter 5 - METHODOLOGY 27
5.1. Preface 27
5.2. Palestinian Hospitals Evaluation 27
5.2.1. Daylight Measurement 28
5.2.2. Interviews 30
5.3. Optimization of the Parameters Affecting Daylight 31
5.3.1. Simulation Inputs 34
5.4. Enhancement of the Studied ICUs 36
Chapter 6 - DATA COLLECTION, RESULTS AND DISCUSSION 37
6.1. Preface 37
6.2. Palestinian Hospital Evaluation 37
6.2.1. Hospital Classification 37
6.2.2. Alahli Hospital 39
6.2.2.1. Lighting Quality 41
6.2.2.2. The Incidence of Delirium 44
6.2.3. Alia Governmental Hospital 44
6.2.3.1. Lighting Quality 47
6.2.3.2. The Incidence of Delirium 49
6.2.4. Palestine Medical Complex 50
6.2.4.1. Lighting Quality 51
6.2.4.2. The Incidence of Delirium 53
6.2.5. Istishari Arab Hospital 54
6.1.5.1. Lighting Quality 56
6.2.5.2. The Incidence of Delirium 57
6.1.6. An-Najah National University Hospital 58
6.2.6.1. Lighting Quality 60
6.2.6.2. The Incidence of Delirium 62
6.3. Optimization of the Parameters Affecting Daylight 63

6.3.1. Simulation Validity Check ... 65
6.3.2. Single/Isolated ICU Room ... 65
6.3.2.1. Orientation ... 65
6.3.2.2. Window Lintel Level Height ... 66
6.3.2.3. Window to Wall Ratio ... 68
6.3.2.4. Walls' Interior Surfaces Material and Colour ... 69
6.3.2.5. Shading Device ... 70
6.3.3. Orientation Scenarios ... 76
6.3.3.1. North ... 77
6.3.3.2. North-East ... 78
6.3.3.3. East ... 79
6.3.3.4. South- East ... 80
6.3.3.5. South- West ... 83
6.3.3.6. West ... 85
6.3.3.7. North- West ... 86
6.3.4. The Two-Bed ICU Room ... 88
6.3.4.1. Window Lintel Level Height ... 88
6.3.4.2. Window to Wall Ratio ... 90
6.3.4.3. Shading Device ... 93
6.3.4.3.1. South ... 93
6.3.4.3.2. North-East ... 94
6.3.4.3.3. East and West ... 94
6.3.4.3.4. North-West ... 95
6.3.4.3.5. South-East ... 96
6.3.4.3.6. South-West ... 97
6.3.5. A Patient Area Within an ICU Ward. ... 99
6.3.5.1. Window Lintel Level Height: ... 100
6.3.5.2. Window to Wall Ratio ... 102
6.3.5.3. Shading Device ... 103
6.3.5.3.1. South ... 103

6.3.5.3.2. North-East ... 104
6.3.5.3.3. East and West ... 104
6.3.5.3.4. North-West ... 105
6.3.5.3.5. South-East ... 106
6.3.5.3.6. South-West ... 107
6.4. Enhancement of the Studied ICUs ... 110
6.4.1. Alahli Hospital ... 110
6.4.2. Alia Governmental Hospital ... 111
6.4.3. Palestine Medical Complex ... 112
6.4.4. Istishari Arab Hospital ... 114
Chapter 7 - CONCLUSION ... 118
7.1. Research Obstacles ... 123
7.2. Recommendations: ... 123
REFERENCES ... 125
1. English References ... 125
a. 2. Arabic Reference ... 133
a. 3. Interviews ... 133
APPENDICES ... 135
Appendix A: Measurement results of indoor and outdoor illuminance achieved by daylight 135
Appendix B: Interviews questions ... 138

List of Figures

Figure 1.1: The research structure 7
Figure 3.1: An example of an ICU patient care zone 16
Figure 4.1: Daylight main components 22
Figure 4.2: Glare types 26
Figure 5.1: UT383 luxmeter 29
Figure 5.2: The method of dividing the space into points for indoor daylight measurement 29
Figure 5.3: Classification of beds' layout cases of the 2 bed-room according to privacy and access to view provision. The selected case is on the right. 33
Figure 5.4: Classification of the beds' layout cases of the ICU single/isolated room and patient zone within a multibed ICU-ward according to privacy and access to view provision. The selected cases are above. 33
Figure 5.5: The steps of the optimization process 34
Figure 6.1: The first-floor plan of Al-Ahli hospital. 40
Figure 6.2: The plan of the ICU of Al-Ahli hospital 40
Figure 6.3: ICU single rooms in Alahli Hospital with a turned-off artificial lighting. 42
Figure 6.4: ICU patient areas in Alahli Hospital where the average daylight factor was measured. 42
Figure 6.5: The third-floor plan of Alia Governmental Hospital 46
Figure 6.6: The plan of the ICU of Alia Governmental Hospital 46
Figure 6.7: ICU patient area with a turned-off artificial lights in Alia Governmental Hospital. . 47
Figure 6.8: ICU patient areas in Alia Governmental Hospital where the average daylight factor was measured 48
Figure 6.9: The first floor plan of Palestine Medical Complex 50
Figure 6.10: The plan of the ICU of Palestine Medical Complex 51
Figure 6.11: ICU patient areas in Palestine Medical Complex where the average daylight factor was measured 52
Figure 6.12: The first floor plan of Istishari Arab Hospital 54
Figure 6.13: The plan of the ICU of Istishari Arab Hospital 55
Figure 6.14: ICU patient area with a turned-off artificial lights in Istishari Arab Hospital. 55

Figure 6.15: ICU patient areas in Istishari Arab Hospital where the average daylight factor was measured. 56
Figure 6.16: The plan of the surgical ICU of An-Najah National University Hospital. 58
Figure 6.17: The second floor plan of An-Najah National University Hospital 58
Figure 6.18: The fourth floor plan of An-Najah National University Hospital. 59
Figure 6.19: A patient area in the surgical ICU of An-Najah National University Hospital 59
Figure 6.20: The plan of the medical ICU of An-Najah National University Hospital. 60
Figure 6.21: ICU patient areas in An-Najah National University Hospital where the average daylight factor was measured. 60
Figure 6.22: ICU patient areas in An-Najah National University Hospital where the average daylight factor was measured. 61
Figure 6.23: The results of the average daylight factor from simulation, measurement and calculations 64
Figure 6.24: Simulation cases of the ICU single/isolated room with orientation change. 65
Figure 6.25: Average daylight factor and annual energy consumption in different orientations of the ICU single/isolated room 66
Figure 6.26: Simulation cases of the ICU single/isolated room with the change of lintel level height 67
Figure 6.27: Average daylight factor and annual energy consumption in different lentil level height in the studied room 67
Figure 6.28 Simulation cases of the studied room with the change of window to wall ratio 68
Figure 6.29: Average daylight factor and annual energy consumption in different window to wall ratios in the ICU single/isolated room 69
Figure 6.30: Average daylight factor and annual energy consumption in different lentil level height in the ICU single/isolated room 70
Figure 6.31 : Simulation cases of the studied room with the change of horizontal shading device level height 71
Figure 6.32: Simulation cases of the studied room with the change of horizontal shading device depth 73
Figure 6.33: The steps of the optimization process of the single/isolated room 75

Figure 6.34: The optimum values of window lintel level height, window to wall ratio and shading device depth that related to each orientation for the ICU single/isolated room 87
Figure 6.35: Simulation results of average daylight factor of the two-bed-ICU room at all orientations according to the change of window lintel level height. 90
Figure 6.36: Simulation results of the annual heating and cooling loads of the two-bed-ICU room at all orientations according to the change of window lintel level height............................. 90
Figure 6.37: Simulation results of average daylight factor of the two-bed ICU room at all orientations according to the change of window to wall ratio. 92
Figure 6.38: Simulation results of the annual heating and cooling loads of the two-bed ICU room at all orientations according to the change of window to wall ratio. 92
Figure 6.39: The optimum values of window lintel level height, window to wall ratio and shading device depth that related to each orientation for the two-bed ICU room 99
Figure 6.40: Simulation results of average daylight factor of the patient area within an ICU ward at all orientations according to the change of window lintel level height........................... 101
Figure 6.41: Simulation results of the annual heating and cooling loads of the patient area within an ICU ward at all orientations according to the change of window lintel level height..... 101
Figure 6.42: Simulation results of average daylight factor of the patient area within an ICU ward at all orientations according to the change of window to wall ratio. 103
Figure 6.43: Simulation results of the annual heating and cooling loads of the patient area within an ICU ward at all orientations according to the change of window to wall ratio............. 103
Figure 6.44: The optimum values of window lintel level height, window to wall ratio and shading device depth that related to each orientation for a patient area within an ICU ward 109
Figure 6.45: The floor plan of the ICU of Alahli Hospital before and after the modification. .. 111
Figure 6.46: The floor plan of the ICU of Alia Governmental Hospital before and after the modification. 112
Figure 6.47: The floor plan of the ICU of Palestine Medical Complex before and after the modification. 113
Figure 6.48: The floor plan of the ICU of Istishari Arab Hospital before and after the modification. 115

Figure 6.49: The floor plan of the surgical ICU of An-Najah National University Hospital before and after the modification. 115
Figure 6.50: The floor plan of the medical ICU of An-Najah National University Hospital before and after the modification. 116
Figure 7.1: The percentage of patients who receive adequate daylight and have access to view in the ICUs of the studied hospitals after modification. 121

List of Tables

Table 5.1: The recommended grid-points number for average daylight factor measurement...... 30
Table 5.2: Simulation models used in the study 32
Table 5.3: Simulation constant parameters.. 36
Table 6.1: Hospitals' classification of the hospitals licensed by the Palestinian Ministry of Health according to location, number of ICU beds and the total hospital bed................................ 38
Table 6.2: The field measurements of the selected patient areas of the ICU in Alahli Hospital.. 43
Table 6.3: The field measurements of the selected patient areas of the ICU in Alia Governmental Hospital.. 49
Table 6.4: The field measurements of the selected patient areas of the ICU in Palestine Medical Complex... 53
Table 6.5: The field measurements of the selected patient areas of the ICU in Istishari Arab Hospital.. 57
Table 6.6: The field measurements of the selected patient areas of the ICU in An-Najah National University Hospital 61
Table 6.7: Measurement, calculation and simulation results of the average daylight factor in the ICU patient's areas of Alahli Hospital and Alia Governmental Hospital............................. 64
Table 6.8: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room according to the orientation change.................................. 65
Table 6.9: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room according to the lintel level height change........................ 67
Table 6.10: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room according to the change of window to wall ratio..... 68
Table 6.11: Simulation results of average daylight factor, the annual heating and cooling loads and the uniformity ratio of the ICU single/isolated room according to the change of light reflectance value. 70
Table 6.12: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room according to the change of shading device level height from window sill height. 72

Table 6.13: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room according to the change of overhang shading device depth of the south oriented window. 74
Table 6.14: General types of shading devices 76
Table 6.15: The proposed shading device types for different orientation scenarios 77
Table 6.16: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at north orientation according to the lintel level height change* 78
Table 6.17: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at north orientation according to the change of window to wall ratio * 78
Table 6.18: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at north-east orientation according to the change of window lintel level height * 78
Table 6.19: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at north -east orientation according to the change of window to wall ratio * 78
Table 6.20: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at north-east orientation according to the change of the vertical shading device depth * 79
Table 6.21: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at east orientation according to the change of window lintel level height * 79
Table 6.22: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at east orientation according to the change of window to wall ratio * 80
Table 6.23: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at east orientation according to the change of the vertical shading device depth * 80

Table 6.24: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south-east orientation according to the change of window lintel level height *......... 81
Table 6.25: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south-east orientation according to the change of window to wall ratio * 81
Table 6.26: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south- east orientation according to the change of the vertical shading device depth * 82
Table 6.27: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south- east orientation according to the change of the horizontal shading device depth *......... 82
Table 6.28: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south- east orientation according to the change of the horizontal shading device depth *......... 82
Table 6.29: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south- east orientation according to the change of the horizontal shading device depth *......... 83
Table 6.30: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south-west orientation according to the change of window lintel level height *......... 83
Table 6.31: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south-west orientation according to the change of window to wall ratio * 83
Table 6.32: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south- west orientation according to the change of the vertical shading device depth * 84
Table 6.33: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south- west orientation according to the change of the horizontal shading device depth *......... 84

Table 6.34: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south- west orientation according to the change of the horizontal shading device depth * 84
Table 6.35: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south- west orientation according to the change of the vertical shading device depth * 85
Table 6.36: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at west orientation according to the change of window lintel level height * 85
Table 6.37: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at west orientation according to the change of window to wall ratio * 85
Table 6.38: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at west orientation according to the change of the vertical shading device depth * 86
Table 6.39: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at north-west orientation according to the change of window lintel level height * 86
Table 6.40: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at north- west orientation according to the change of window to wall ratio * 86
Table 6.41: Simulation results of average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at west orientation according to the change of the vertical shading device depth * 87
Table 6.42: Simulation results of average daylight factor and the annual heating and cooling loads of the two-bed-ICU room at all orientations according to the change of window lintel level height * 89
Table 6.43: Simulation results of average daylight factor and the annual heating and cooling loads of the two-bed ICU room at all orientations according to the change of window to wall ratio. 91

Table 6.44: Simulation results of average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south orientation according to the change of overhang shading device's depth * 93
Table 6.45: Simulation results of average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south orientation according to the change of overhang shading device's depth * 94
Table 6.46: Simulation results of average daylight factor and the annual heating and cooling loads of the two-bed ICU room at north-east orientation according to the change of the vertical shading device's depth * 94
Table 6.47: Simulation results of average daylight factor and the annual heating and cooling loads of the two-bed ICU room at east orientation according to the change of the vertical shading device depth * 95
Table 6.48: Simulation results of average daylight factor and the annual heating and cooling loads of the two-bed ICU room at west orientation according to the change of the vertical shading device depth * 95
Table 6.49: Simulation results of average daylight factor and the annual heating and cooling loads of the two-bed ICU room at north-west orientation according to the change of the vertical shading device depth * 95
Table 6.50: Simulation results of average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south-east orientation according to the change of the vertical shading device depth * 96
Table 6.51: Simulation results of average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south- west orientation according to the change of the horizontal shading device depth * 96
Table 6.52: Simulation results of average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south- east orientation according to the change of the horizontal shading device depth * 97
Table 6.53: Simulation results of average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south-east orientation according to the change of the vertical shading device depth * 97

Table 6.54: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south-west orientation according to the change of the vertical shading device's depth *.. 98
Table 6.55: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south- west orientation according to the change of the horizontal shading device's depth * 98
Table 6.56: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south- west orientation according to the change of the horizontal shading device's depth * 98
Table 6.57: Simulation results of average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at all orientations according to the change of window lintel level height *.. 100
Table 6.58: Simulation results of average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at all orientations according to the change of window to wall ratio. 102
Table 6.59: Simulation results of average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south orientation according to the change of overhang shading device’s depth * 104
Table 6.60: Simulation results of average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at north-east orientation according to the change of the vertical shading device’s depth * 104
Table 6.61: Simulation results of average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at east orientation according to the change of the vertical shading device depth * 105
Table 6.62: Simulation results of average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at west orientation according to the change of the vertical shading device depth * 105
Table 6.63: Simulation results of average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at north-west orientation according to the change of the vertical shading device depth * 105

Table 6.64: Simulation results of average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south-east orientation according to the change of the vertical shading device depth * 106
Table 6.65: Simulation results of average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south- west orientation according to the change of the horizontal shading device depth * 106
Table 6.66: Simulation results of average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south- east orientation according to the change of the horizontal shading device depth * 107
Table 6.67: Simulation results of average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south-east orientation according to the change of the vertical shading device depth * 107
Table 6.68: Simulation results of average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south-west orientation according to the change of the vertical shading device depth * 108
Table 6.69: Simulation results of average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south- west orientation according to the change of the horizontal shading device depth * 108
Table 6.70: Simulation results of average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south- west orientation according to the change of the horizontal shading device depth * 108
Table 6.71: Simulation results of average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south-west orientation according to the change of the vertical shading device depth * 108
Table 6.72: The differences between the ICU design of Alahli hospital before and after modification 110
Table 6.73: The differences between the ICU design of Alia Governmental hospital before and after modification 112
Table 6.74: The differences between the ICU design of Palestine Medical Complex before and after modification 113

Table 6.75: The differences between the ICU design of Istishari Arab Hospital before and after modification ... 114
Table 6.76: The differences between the ICU design of An-Najah National University Hospital before and after modification ... 117
Table 7.1: The optimum values of window lintel level height, window to wall ratio, light reflectance value and shading device depth that related to each orientation for an ICU single/isolated room. ... 119
Table 7.2: The optimum values of window lintel level height, window to wall ratio, light reflectance value and shading device depth that related to each orientation for an ICU two-bed room. ... 119
Table 7.3: The optimum values of window lintel level height, window to wall ratio, light reflectance value and shading device depth that related to each orientation a patient area within an ICU ward. ... 120

Chapter 1 - INTRODUCTION

1.1. Introduction

The concept of 'healing environment' becomes a widespread idea in the design of hospitals. Which are complex systems where there are many factors influencing the patient's outcome at the same time affecting the effectiveness and the wellbeing of the healthcare providers. Many studies showed that hospital design and physical environment are closely linked to the stress levels of the healthcare providers, patients and their families as well as to the staff effectiveness and patient safety (Rubert, et al., 2007); (Jongerden, et al., 2013); (Coomber, et al., 2002); (Shepley, et al., 2012). This is particularly essential in critically ill patients who are at high risk of developing a disturbance of mental abilities such as delirium, and more precisely when the indoor environment lacks natural light and accessibility to outdoor views (Fuchs, et al., 2020).

Since the 1990s, there has been a great enhancement of healthcare which is mainly due to the development of practicing medicine that is based on evidence 'evidence-based medicine'. Which started as a call for medical decisions depending on critical thinking and integrated to personal clinical expertise, related scientific research and patient's preferences and satisfaction (Shedler, 2020). Although a lot is known in this field, it is still unclear how this can be applied to hospital design and its relation to the healthcare system. Evidence-based design provides the focus on how designs can be best utilized to help patients recovery while providing a safe environment for the staff allowing them to perform better (Ulrich, et al., 2004); (Butt & Khan, 2018). This focus is believed to improve the overall healthcare quality and reducing costs (Iyendo & Alibaba, 2014). Daylight and natural views are of the most important physical aspects that can positively affect patients and staff as it has therapeutic and healing properties (Rubert, et al., 2007); (Aripin, 2007); (Rubert, et al., 2007) (Münch, et al., 2020).

Daylight maximizes the visual performance more than most artificial lightning does as it has a broad spectrum of wavelength delivered in large amounts (Knoop, et al., 2020); (Boyce, et al., 2003). It is a cheap source of light and has a positive impact on patients, especially critically ill patients (Aripin, 2007); (Vahedian-Azimi, et al., 2020). On the other side, there are limitations to the use of daylight in hospitals. First, daylight can cause visual discomfort through glare and distraction. It can as well decrease stimuli to the visual system by producing reflections and shadows. Second, the fluctuation in the source of daylight due to weather and climate circumstances (Boyce, et al., 2003); (Shen & Tzempelikos, 2014).

The intensive care unit (ICU) is the most complex place in the hospital, where patients with critical illnesses are treated, and most at risk (Faiola & Newlon, 2011); (Hamilton, 2020). This makes it a high-stress place for patients, medical staff and even for patients' families. Therefore, healthcare designers must consider all factors that enhance the ICU environment in terms of reducing stress and improving the efficiency of treatment (Butt & Khan, 2018). Indeed, physical factors such as daylight and access to outdoor views play a positive role in creating this 'healing environment' for users (Rubert, et al., 2007); (Rafeeq & Mustafa, 2020). Consequently, the appropriate size and characteristics of windows are essential aspects to be considered to ensure that patients are not deprived of seeing the outside and enjoying natural light, which decreases their sense of isolation and therefore decreases the incidence of delirium. (Rubert, et al., 2007); (Anderson, et al., 2020).

On the other hand, window design has a significant impact on the indoor temperature, which in turn affects the heating and cooling loads (Tao, et al., 2020) ; (Yao, 2014); (Vanhoutteghem, et al., 2015). Therefore, the balance between the daylight and the heating and cooling loads is crucial to have a better function. How to maintain this balance is still unclear taking into consideration that the design is variable according to the geographic and climatic status of hospital location.

The climate of Palestine is generally warm with better daylight sources in winter and autumn when compared to a western country. No previous studies were found in Palestine investigating the effect of the ICU design on lightening achieved by daylight and the access to the outdoor environment through windows.

Simulation is one of the most important methods used to assess and enhance daylighting. Most previous studies based on assumptions of some parameters to investigate the impact of others; (Sherif, et al., 2015) investigated the appropriate window size and the shading system of an ICU room in different orientation while wall reflectance and window level are constant, (Mangkuto, et al., 2016) conducted a simulation study to clarify the impact of window-to-wall ratio, wall reflectance, and window orientation of simple buildings in the tropical climate on different daylight metrics and the energy consumption for artificial lighting without considering the use of shading device, and while the window level is constant. (Sherif, et al., 2016) conducted a study to determine the appropriate shapes of the horizontal blind slats for a hospital room that achieve the best daylighting as well as patient access to outside view when the orientation is assumed toward the south, and window to wall ratio, window level and wall reflectance are constant. (Englezou & Michael, 2020) used a simulation tool to investigate the impact of different window configurations and shading devices of two inpatient rooms on daylight performance in Cyprus when window orientation is assumed toward south. (Shikder, et al., 2010) conducted a parametric simulation process to optimize daylight-window of a hospital room in terms of daylighting and energy consumption focusing on window width, window sill level, window little level and solar shading depth, while the orientation was assumed constant and the study assumed the acceptable value of the average daylight factor as 2%, which is below the acceptable value for healthcare rooms (BREEAM, 2011).

This study used DesignBuilder simulation tool to optimize the parameters that affect daylight by following successive steps so that the result of each step was used as a simulation input for the next one; to consider the relationship of the parameters to each other. This research aims to propose recommendations to be considered in the design of ICU single room, two-bed room and a patient area within an ICU ward in Palestine to achieve desirable lighting and access to outside view while reducing the energy consumed for heating and cooling as much as possible.

1.2. Scope of the Study

The study focuses on the ICUs of the Palestinian hospitals in terms of analysis and evaluation in order to reach ICU-design recommendations to optimize the amount of daylight as well as the energy consumption for heating and cooling without restricting access to the outside view. These recommendations can be generalized to be followed in general patients' areas in Palestine since the required average daylight factor is the same. Moreover, they can be generalized to other Mediterranean countries as well due to the similarity of the solar path.

1.3. Problem Statement

There is a lack of studies related to the design of ICU in light of the provision of appropriate daylight and natural views in Palestine. This results in the production of random designs that are not compliant with the right standards and guidelines. These designs are not compatible with the surrounding environment in the sense of improper utilization of natural lighting resources. The study proposes a set of recommendations that can improve the ICU designs in Palestine to help to achieve a healing environment while considering both physical and functional aspects.

This study answers the following main question:

What are the ideal conditions of the ICU design in Palestine that achieve the optimal daylight and access to view as well as the minimal heating and cooling loads to achieve a healing environment?

The study also answers the following sub-questions:

1. Does the average daylight factor in the ICUs of the Palestinian hospitals achieve the standard value of 3% (Leccese, et al., 2016); (BREEAM, 2011)? Do the ICU patients have an access to the outside views in the Palestinian hospitals?
2. What is the orientation of the window that achieves the optimal daylight as well as minimal heating and cooling loads?
3. What are the values of window lintel level height, window to wall ratio, light reflectance value that achieve the optimal daylight and access to view as well as the minimal heating and cooling loads at all orientation scenarios?
4. What are the optimum specifications of the shading device for each orientation scenario that provide the optimal daylighting and minimal energy consumption without restricting the access to view?
5. How can the situation of the ICUs of the studied hospitals in Palestine be improved in terms of daylight and access to view using the results of the optimum values of the parameters that affect daylight?

1.3. Research Objectives

General Objective: To determine the ideal conditions of the ICU design in Palestine that achieve the optimal daylight and access to view as well as the minimal heating and cooling loads to achieve a healing environment.

Specific Objective:

1. To determine whether the average daylight factor in the ICUs of the Palestinian hospitals achieve the standard value of 3% (Leccese, et al., 2016); (BREEAM, 2011).
2. To investigate patients' accessibility to the outside views in the ICUs Palestinian hospitals?
3. To identify the orientation of the window that achieves the optimal daylight and access to view as well as the minimal heating and cooling loads.
4. To identify the values of window lintel level height, window to wall ratio, light reflectance value that achieve the optimal daylight and access to view as well as minimal heating and cooling loads at all orientation scenarios.
5. To identify the optimum specifications of the shading device for each orientation scenario that provide the optimal daylighting and minimal energy consumption without restricting the access to view.
6. To investigate the enhancement potential of the ICU designs of the studied hospitals in Palestine in terms of daylight and access to view through using the results of the optimum values of the parameters that affect daylight.

`

1.4. Research Structure

The research includes 7 chapters: the first is the introduction, the second, the third and the fourth present the literature review and the needed background information. Chapter 5 presents the methodology used in data collection and analysis and chapters 6 and 7 present the results and conclusion respectively. Figure 1.1 below shows the research structure and the main contents of each chapter.

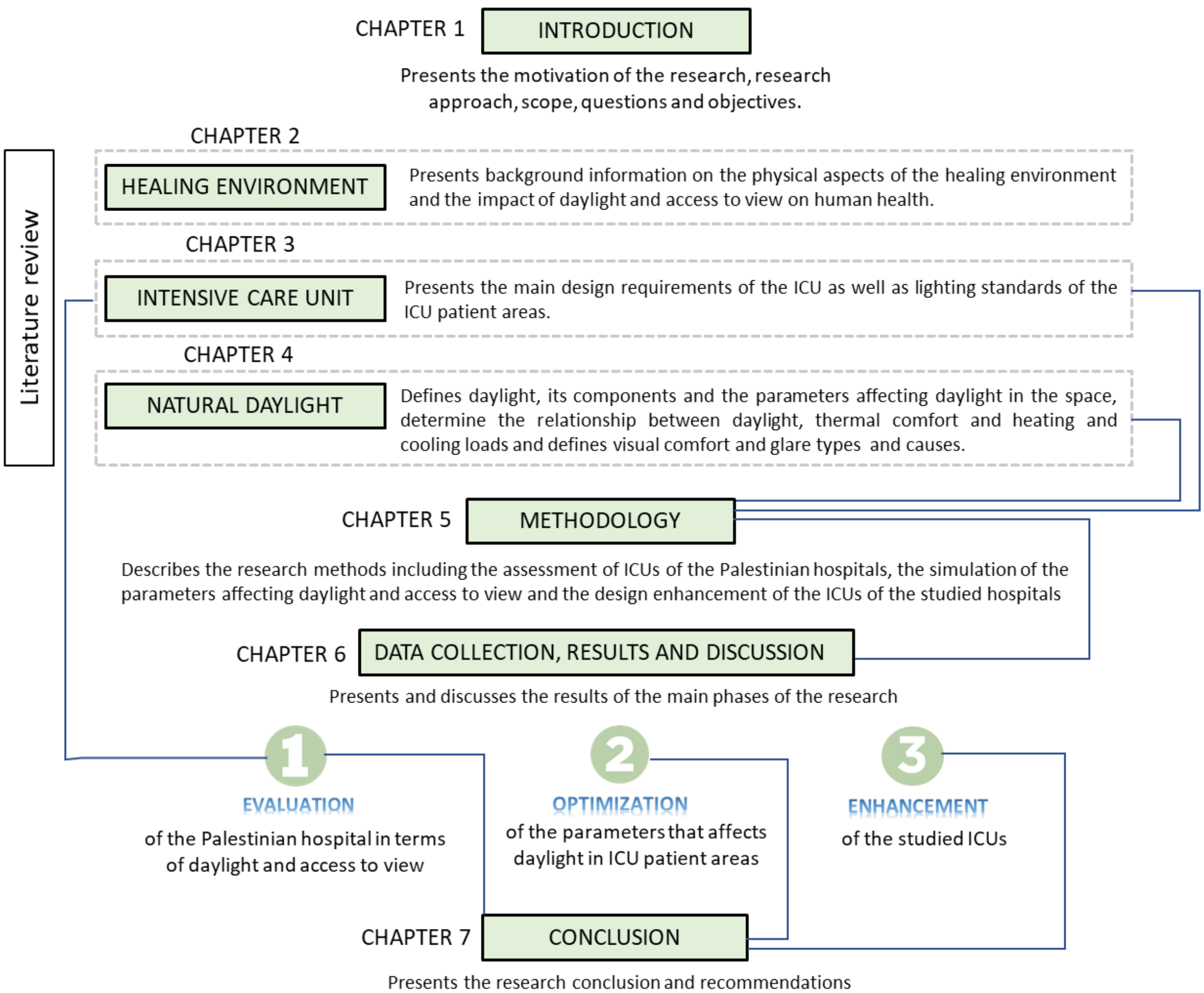


Figure 1.1: The research structure

Chapter 2 - HEALING ENVIRONMENTS

2.1. Preface

This chapter presents a summary of literature that focused on the importance of providing a healing environment for patients and the need to provide natural lighting as well as access to view for patients and medical staff.

2.2. Healing Environments

Providing ‘a healing environment’, which is defined as a healthy environment that is physically and psychologically appropriate, should be taken into account in the design of healthcare facilities (Lawson, 2010); (Rafeeq & Mustafa, 2020). A healing environment would enhance patients’ outcomes and increase staff productivity and performance (Aripin, 2006); (Aripin, 2007); (Brambilla, et al., 2019); (Rafeeq & Mustafa, 2020). Applying that requires a comprehensive study of psychological, physical and social aspects of the healthcare building and its occupants (Brambilla, et al., 2019). Some studies classified thermal comfort, natural light, indoor air quality, noise control, visual comfort and access to natural views as physical aspects that should be considered in the healthcare design process (Brambilla, et al., 2019); (Lawson, 2010); (Shikder, et al., 2010); (Ulrich, 1984); (Jamshidi, et al., 2019); (Zijlstra, et al., 2020). This makes the hospital design a complex mission that is not only limited to functional aspect but also encompasses physiological and social aspects. This task might be more critical when the design targets patients with restricted mobility particularly patients in ICUs. In this case, providing the appropriate indoor environment and communication with outdoor nature would be a crucial design priority (Vahedian-Azimi, et al., 2020). Hospitals in general are stressful places for patients and visitors mainly due to fear of death, pain, noises and odors. Therefore, providing a better healing environment would help them relieve the stress and would also improve the outcome (Alzubaidi, et al., 2013).

2.3. Daylight and Human Health

Recent studies have shown a strong relationship between daylight and human physical, psychological and mental health; it was found that daylighting has an impact on reducing depression, improving alertness, reducing fatigue and reducing the consumption of killer pain drugs among hospitalized patients (Ulrich, et al., 2004); (Knoop, et al., 2020); (Jamshidi, et al., 2019); (Alzubaidi, et al., 2013); (Wang & Chen, 2020). Whereas, the lack of exposure to natural daylight has a bad influence on human health and may cause delirium, stress, seasonal affective disorder(SAD): a mood disorder that is caused by the shortening of daylight hours in winter (Nussbaumer-Streit, et al., 2019) (Beute & de Kort, 2018) (Vyveganathan, et al., 2019) and Vitamin D deficiency which is linked to many serious complications such as bone diseases, cancer, cardiovascular diseases, autism, diabetes, multiple sclerosis and schizophrenia (Kočovská, et al., 2017) (Amrein, et al., 2020);(Boubekri, 2007); (Osmancevic, et al., 2009). Furthermore, the lack of daylight may affect the circadian rhythms badly, and therefore result in depression, sleep problems and immune deficiencies (Walker, et al., 2020) (Haspel, et al., 2020).

Daylight has also great impacts on the patient's recovery; many reports support the therapeutic use of sunlight in treating diseases and enhance the wellbeing of the patients. This goes back into the 19th century when sunlight exposure was one of the modalities of treatment for tuberculosis patients (Alzubaidi, et al., 2013). Many recent studies have investigated new relationships between lighting and patients' recovery. For example, Choi (2007) found that the naturally well-lit rooms might fasten the patients' recovery and reduce the hospital stay when compared to rooms with lower levels of luminance (Choi, 2007). Furthermore, it was found that light therapy using both daylight and artificial light, has been shown to enhance sleep efficiency and rest/activity rhythm in patients with Alzheimer's disease, and manage as well their behavioral disturbances (Hanforda & Figueiro, 2012); (Figueiro, 2017). Exposure to sunlight is considered also a powerful treatment method for certain skin disorders such as herpes and psoriasis (Osmancevic, et al., 2009) and has been shown to have a positive impact on reducing the consumption of killer pain drugs among hospitalized patients (Alzubaidi, et al., 2013).

2.4. Access to View and Human Health

Having a natural view has a positive impact on the patients as it reduces stress and decreases pain by distracting them from focusing on their suffering (Brambilla, et al., 2019). The power of natural views has been shown to significantly recover stress within three to five minutes at most (Zimring, et al., 2004). Furthermore, patients with nature-view were found to have shorter recovery time after surgery, less negative nurses' complaints, lower doses of analgesia and a lower rate of minor postsurgical complications when compared to patients with wall-view (Sherif, et al., 2014);(Ulrich, 1984). Visual contact with the outside has also a great influence on reducing the feeling of isolation and strengthening patients' interest in the surrounding environment (Frumkin, et al., 2017); (Iyendo, 2004). Therefore, site and orientation selection is a basic decision for healthcare designers (Aripin, 2007) as well as window sill height, which is also a significant parameter that affects the connection ability to the outdoor nature, it should be proportional to beds' level and human height (Shepley, et al., 2012).

2.5. Conclusion

Providing a healing environment is essential for patients to improve their outcome, increase their satisfaction, reduce stress and positively affect their physical, psychological and mental health. This healing environment can be achieved through enhancing the physical aspects of the space, such as daylighting and access to view, which have a significant impact on patients, particularly critically ill patients.

Chapter 3 - INTENSIVE CARE UNIT (ICU)

3.1. Preface

This chapter presents background information on the ICU, including its definition, size and functional design requirements that must be met in the ICU. Furthermore, it presents the lighting standard of the ICU and the required average daylight factor of ICU patients' areas.

Moreover, this chapter presents a summary of literature that focused on the impact of daylight and access to view on ICU patients and staff.

The information included in this chapter served in establishing the methodology and the assumptions of the hospitals' evaluation, modification and the optimization process in chapter 5 and 6.

3.2. ICU Design

The intensive care unit (ICU) is "a specialized section of a hospital that provides comprehensive and continuous care (treatment and monitoring) for persons who are critically ill or in an unstable condition and who can benefit from treatment" (Christoforos, 2012). ICU is the proper place for patients who need advanced respiratory support or who require the support of more than one organ system as well as patients with chronic weakness in one or more organ systems enough to limit routine activities (Bion & Dennis, 2016).

Not long ago, ICU design was limited to the functional aspect that would only consider medical requirements for patients and staff convenience. This design of the past was utilitarian restricting family visits and dehumanized the experience of patients. (Rubert, et al., 2007). These days, healthcare designers try to achieve the best function with the best services and facilities at the lowest costs, to gain maximum effectiveness and efficiency. (Brambilla, et al., 2019).

Therefore, the design process expands to include social and physical aspects that are based on evidence to create a healing environment of the ICU on one side (Ulrich, et al., 2008), and economic aspects to control costs on the other (Brambilla, et al., 2019). ICU design should be flexible to comply with the changing of healthcare settings and technological development (Thompson, et al., 2012). This is in line with some researchers' prediction that 80% of the present medical knowledge and technology will change in the next 20 years, where healthcare functions must be flexible to adapt to this evolution (Brambilla, et al., 2019). Due to this continuous change, ICU design went through two phases:

- Centralized design: the traditional design, where a single workstation is located at the center of the critical care unit, from which all patients within the unit can be observed. This design has been used traditionally, due to the use of central monitors and single paper medical records (Thompson, et al., 2012).

- Decentralized design: technological development and the changes of information systems lead to the use of digital records in many places at the same time, medical staff members become prevalent and closer to the bedside than before, presence of patients' families becomes easier and functional arrangements become decentralized (Thompson, et al., 2012).

The design of ICU is not a simple task, due to the continuous and emergency receiving of daily patients and using complex technologies and systems while dealing with high-risk conditions of critical illnesses (Brambilla, et al., 2019); (Faiola & Newlon, 2011); (Thompson, et al., 2012). This complexity of these requirements demands a precise function that takes all aspects into account.

3.2.1. ICU Sizing

Based on its role, ICU has 3 levels, which are identified according to its size (number of beds), facilities and services as well as the severity of patients' illnesses and staff expertise. Regardless of the operational, staffing, equipment and design requirements of each level, level I should have beds number that complies with the ICU demand, while level II should contain at least six staffed and equipped beds and level III should contain at least 8 staffed and equipped beds and sometimes the number exceeds 50 as per the clinical activity. However, in the case of large ICU, ICU should be divided to separate areas for 8-12 patients to avoid management difficulties (FICANZCA, 2011).

3.2.2. Functional Design of ICU

ICU mainly consists of four zones: The Patient Care Zone, The Clinical Support Zone, The Unit Support Zone and Family Support Zone (Thompson, et al., 2012); (Butt & Khan, 2018).

1. The Patient Care Zone:

The areas where patients are provided direct medical care which includes patients' rooms and the adjacent areas. The patient room contains a patient bed, anteroom, toilet, fixed equipment and closets (Thompson, et al., 2012); (Butt & Khan, 2018). It will be socially helpful for patients to promote the presence of their families by liberating family visits and allocating a suitable place for visitors (Rubert, et al., 2007); (Butt & Khan, 2018). The patient room may be a multi-bed or a single room. It was found that a single room is better for patients' safety since the possibility of transmission of infection in a single room is lower by half compared to a multibed (Teltsch, et al., 2011). It also reduces noise (Konkani, et al., 2014) , allows patients to receive appropriate daylight (White, 2003) and enhances patients' sleep as well as privacy (Rubert, et al., 2007). However, providing ICU single rooms seems to be challenging when space and financial factors are limited (White, 2003).

The patient area should be at least $20m^2$ per bed in multi-bed rooms with an unobstructed corridor of 2.5m width and $25m^2$ for single rooms and isolation rooms plus an anteroom of a minimum area of $1.8m^2$ for each bed (FICANZCA, 2011); (SCCM, 1995) (ICS, 1997). Clearance should be at least 1.20 m from the ICU bed head and foot, and at least 1.8m on each side. These areas should be considered in the patient rooms as well as furnishing space (i.e: critical care bed, patient chair, visitor chair, secure storage, closet, trash containers and medical waste containers), toilet area, space for equipment and sufficient area for personal movements (Thompson, et al., 2012) (Butt & Khan, 2018).

Designers should also pay attention to doors and windows design, doors should be hard, unbreakable and wide enough to comply with the fast movements of beds, equipment and staff. As for windows, they must allow a good amount of daylight and outdoor views (Christoforos, 2012); (Butt & Khan, 2018) ; (Thompson, et al., 2012). Each patient bed area should have at least one appropriate-size window. However, in the case of the observational necessity for the patient to face the interior, mirrors can be used on walls or ceiling to provide an alternative way to see the outdoor view and daylight reflection. Blue and green colors are recommended for painting and decoration of patient rooms. (Thompson, et al., 2012). Figure 3.1 provides an example of a patient care zone layout that includes the general needs for an ICU patient.

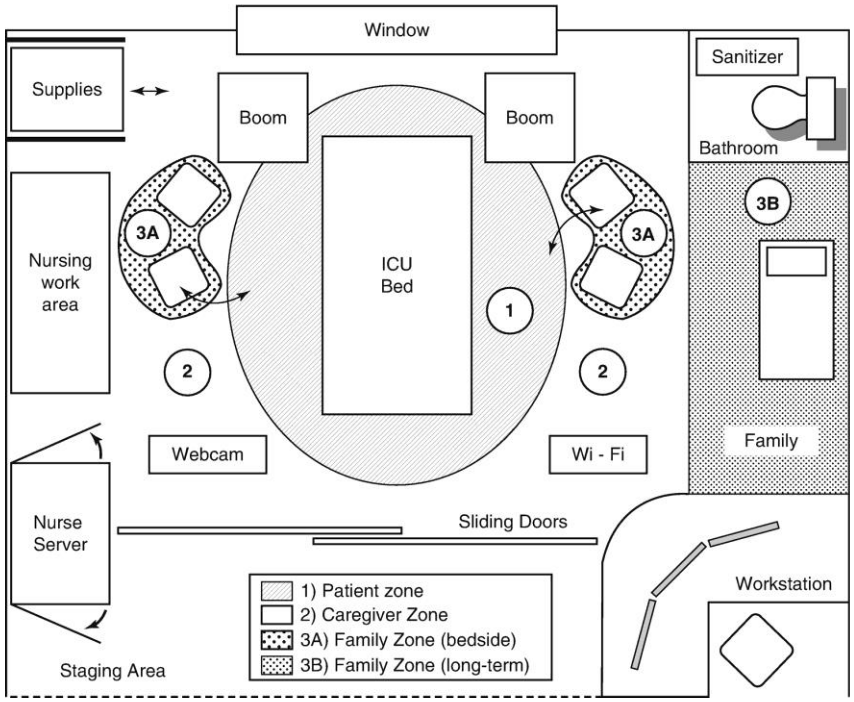


Figure 3.1: An example of an ICU patient care zone

Source: (Anderson & Halpern, 2016)

2. Clinical Support Zone:

The zone where diagnosis and treatment practices are done for patients. Although some of these practices may be placed in the patient care zone, others may require a separate space in the ICU or other places in the hospital. This zone includes 1) Emergency eyewash station to be used in emergency cases of ICU workers exposure to dangerous fluids. 2) Teamwork areas, where health professionals can interact and discuss medical issues. These areas should be supported by storage for references, manuals, computers, telephones and other related facilities. 3) Laboratory, which may be a central one for the whole hospital or a satellite one within the ICU. Regardless of its location, ICU must have easy access 24 hours to the laboratory. 4) Pharmacy, like the laboratory, whether it is for the whole hospital or satellite in the ICU, it must be accessible all the time for ICU. 5) Medication room, where medication is prepared by ICU staff. It contains a specific area for patients, medication storage, hot and cold-water sink and other related equipment and tools. This is to ensure medication validity, medical tools disposal and patients and staff safety (Thompson, et al., 2012); (Butt & Khan, 2018). The medication room area should be at least 50m2 (Christoforos, 2012). Appropriate visualization is crucial to medication room through windows, especially patients' areas. 6) Imaging: sufficient storage for portable imaging devices should be provided in the unit. 7) Respiratory support space, where equipment such as oxygen tanks and ventilators are stored. 8) Specialized procedure areas, patients' areas should be ready to accommodate emergency medical procedures at any time. However, specialized areas may be provided in the ICU for this task. 9) A place for emergency carts, they must be visible and easy to move, therefore, they can be put along the corridors. 10) A storage for nonemergency equipment, such as wheelchairs. 11) Hazardous waste storage. 12) Patient nourishment space, where food and drink are prepared for patients and staff. (Thompson, et al., 2012); (Butt & Khan, 2018).

3. Unit Support Zone:

This zone includes administration and staff rooms, offices, conference room, On-call rooms, staff lounge, staff restrooms, lockers, supplies, clean workrooms, solid workrooms and housekeeping rooms (Thompson, et al., 2012); (Butt & Khan, 2018).

4. Family Support Rooms:

As mentioned before, family presence is supportive and helpful for patients (Rubert, et al., 2007). Designers should take the family's needs into accounts, such as providing appropriate spaces for rest and sleeping and nourishment (Thompson, et al., 2012); (Butt & Khan, 2018).

3.3. Lighting Design Standards of ICU

Natural lighting is strongly recommended for ICU different functions. Therefore, high attention must be paid to window design to provide the optimal daylight amount and uniformity. It is also important to minimize the discomfort glare as possible. Therefore, a balance between daylight and artificial light should be created to achieve the required illumination, especially at night-time. In general, the required value of the average daylight factor for hospital wards (without the need of turning the artificial lights on) is 5% (Mohelnikova & Hirs, 2016). While it is acceptable at 3% as the minimum average value, which is also suitable for laboratories as well as the examination rooms (Leccese, et al., 2016); (BREEAM, 2011) and corridors, hallways, stairs and offices require 1%. Other spaces in the hospital require 2% as minimum average values (Leccese, et al., 2016).

Whereas, the general luminance of the ICU during the daytime should be at most 325 lux, which is sufficient for usual nursing tasks. While it should be at most 75 lux in the night to enable patients to sleep well, and can be raised to 215 lux for short times when needed. Task lighting for emergency procedures should be provided with a luminance of at least 1615 lux which should be shadow-free and located directly above the patient (Christoforos, 2012).

It is recommended to give patients control over both, artificial and natural lights through the capability to open or close windows, control shading devices if any, and control the luminance level of artificial lights (Rubert, et al., 2007); (Thompson, et al., 2012).

3.4. The Impact of Daylight and Access to View on ICU Patients and Staff

There has been good evidence on the impact of the ICU environment on patients' outcome and staff satisfaction; Rubert, Long and Hutchinson (2007) and Jongerden, et al. (2013) found that physical aspects such as noise, light, color, air quality and outdoor landscape have a significant influence on ICU patients' recovery (Rubert, et al., 2007) ; (Jongerden, et al., 2013). Furthermore, it was found that the physical environment is one of the top three stressors patients experience in the ICU. This was also evident in the ICU doctors when one-third of them were found to suffer from high-stress levels (Coomber, et al., 2002); (Shepley, et al., 2012).

Daylight is one of the most important physical aspects affecting patients and medical staff in ICU. In addition to the positive effects mentioned earlier of the daylight on patients (i.e: reducing stress and depression, decreasing the request of pain drugs and reducing the length of stay), natural lighting has a greater impact on critically ill patients who have a very high risk of delirium (Anderson, et al., 2020). Delirium is defined as "a disturbance of consciousness with inattention, accompanied by a change in cognition or perceptual disturbance that develops over a short period (hours to days) and fluctuates over time" (Simons, 2018). The prevalence of delirium in ICU patients can be as high as 80% (Simons, 2018); (Vasilevskis, et al., 2018); (Ouimet, et al., 2007); (Fuchs, et al., 2020). It was found that ICU delirium increases ICU length of stay (Vahedian-Azimi, et al., 2020); (Fuchs, et al., 2020); (Simons, 2018); (Ouimet, et al., 2007), maximizes the risk of persistent cognitive impairment after discharge (Simons, 2018), is responsible for 10% of dementia cases (Fuchs, et al., 2020) and is highly correlated with poor patients outcomes (Vahedian-Azimi, et al., 2020); (Skrobik, 2009); (Chong, et al., 2013). Moreover, ICU patients with delirium were found to have higher mortality than others without and more likely to die in hospital (Fuchs, et al., 2020); (Vahedian-Azimi, et al., 2020); (Ouimet, et al., 2007); (Vasilevskis, et al., 2018).

Delirium is also significantly correlated with substantial costs (Weinrebe, et al., 2016); (Lee & Kim, 2016); as delirium can increase the ICU cost by 39% and the hospital costs by 31%

(Milbrandt, et al., 2004). Recent studies investigated a notable relationship between daylight and the occurrence of delirium. For example, Hashemighouchani, et al. (2020) and Rompaey, et al. (2009) found that isolation and absence of daylight are major risk factors for ICU delirium (Hashemighouchani, et al., 2020); (Rompaey, et al., 2009), Vyveganathan, et al. (2019) and Skrobik (2009) found that visible daylight results in a reduction of incidence of delirium (Vyveganathan, et al., 2019); (Skrobik, 2009), Chong, et al. (2013) have shown evidence for the clinical benefits of bright light therapy of delirium and its impact on improving the functional outcomes of patients with delirium (Chong, et al., 2013) and Simon (2018) found that delirium is more likely (2-3 times) to occur and the incidence of delusions and hallucinations is more than twice in a windowless unit compared to a unit with translucent window (Simons, 2018).

The positive effect of natural light is not limited to patients but extends to medical staff as well. It was found that increasing daylight and window views have a positive impact on ICU staff absenteeism and reduce medical errors (Shepley, et al., 2012). Physical aspects of ICU design (i.e: daylight and natural views) have a significant impact on patients and staff outcomes. Access to daylight can significantly improve nurses' productivity (Guenther & Hall, 2007), reducing job burnout (Mourshed & Zhao, 2012); increase their satisfaction and has a good impact on their recruitment and retention. A survey study was conducted in Hamad General Hospital in Doha, Qatar, emphasizes this positive effect of daylight on staff satisfaction, where 79% of the medical staff ensure their belief in the importance of daylight in patient's room to help them do their job easily, including treating, diagnosing (i.e.: noticing the changing in patient's skin color) and monitoring patients (Alzubaidi, et al., 2013). The architectural design of healthcare rooms and ICU should be an evidence-based design that considers all functional and physical aspects to meet patients, staff, and visitors' physical, psychological and mental requirements.

3.5. Conclusion

The design of the ICU is a complex matter that must take all aspects into account. It requires thorough thinking of the needs of patients and medical staff. Besides the functional requirements, great attention must be paid to the indoor environment quality including the provision of adequate daylight and access to the outside view. These aspects greatly influence the outcomes of ICU patients and the incidence of delirium among them. Moreover, it is closely related to the productivity and satisfaction of the medical staff.

Chapter 4 - NATURAL LIGHT

4.1. Preface

Daylight definition and daylight factor measurement-method are presented in this chapter, in addition to a summary of the previous studies that discussed the factors affecting daylight and access to view in patients' rooms and the associated problems with providing daylight, such as increasing heat gain hence increasing energy consumed for heating and cooling, and the occurrence of glare.

4.2. Daylight Measurement

Daylight is a combination of direct sunlight, reflected light from the ground and skylight, which is the scattered light by the air molecules, aerosols and different particles (Saradj, et al., 2014). Natural light in a certain space is provided by three main components: sky component, internally reflected component and externally reflected component (Mohelnikova & Hirs, 2016) as shown in Figure 4.1.

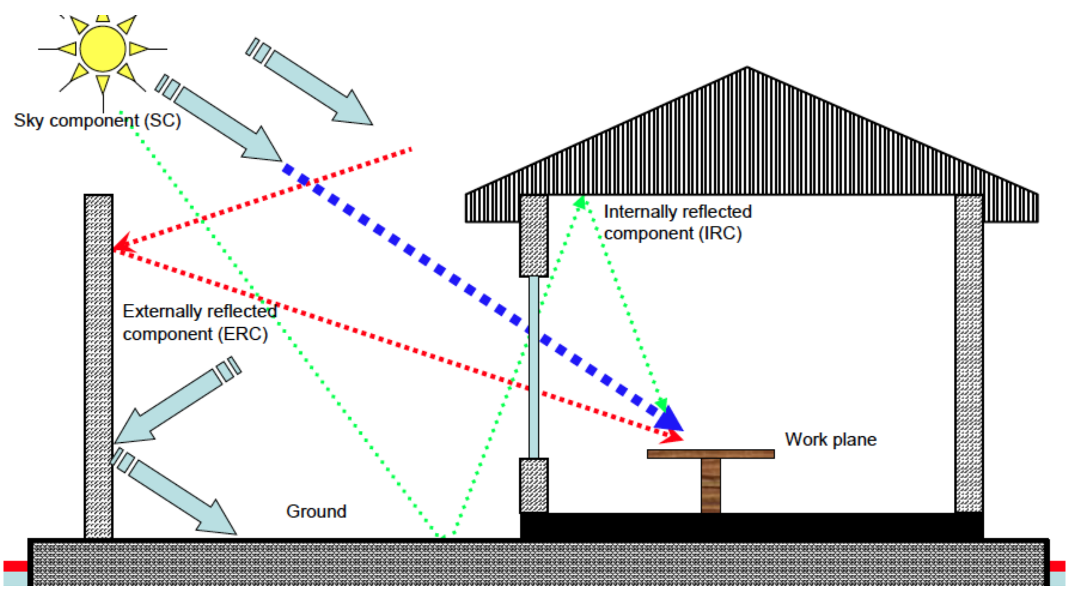


Figure 4.1: Daylight main components
(Source: https://www.pinterest.com/pin/707346685201862364/?autologin=true)

The common method to evaluate the internal daylight is using daylight factor (DF), which is the ratio of the interior luminance to the exterior luminance under overcast or uniform sky. The required daylight factor varies according to the function of the building. (Kubba, 2012).

4.3. Parameters Affecting Natural Light in Healthcare Rooms

Designing a healthcare building should ensure appropriate daylight, while at the same time minimizes the heating and cooling loads as well as visual problems such as glare. To ensure the optimum daylight in a healthcare room, essential parameters should be taken into account:

1. The orientation of windows: the selection of the orientation is the first decision and the most important priority in the healthcare room design. It would affect other parameters such as the shape and the size of the window opening and the dimensions and placement of shading devices (Aripin, 2007); (Pai & Siddhartha, 2015); (Kaminska, 2020). Access to a good view (i.e. natural view) is also a fundamental issue that should be considered in orientation selection. It was found that access to a good view has therapeutic influences on patients and has a positive effect on their psychological, physical and mental statuses (Ulrich, 1984); (Raanaas, et al., 2012); (Chavoshani, et al., 2017).
2. Window design: the design of windows in healthcare room has a direct impact on the amount of transmitted daylight and the thermal comfort for users, it would subsequently affect lighting, heating and cooling loads on one hand, and patients' satisfaction and health situation on the other (Shikder, et al., 2010); (Maleki & Dehghan, 2020) ; (Cesari, et al., 2018). Window designing determines the following parameters: window size, its sill and lintel level height and the properties of glazing system (i.e. roughness, number of layers and color) that would affect the transmittance of glass (Aripin, 2007);

(Shikder, et al., 2010); (Pai & Siddhartha, 2015); (Maleki & Dehghan, 2020); (Cesari, et al., 2018);

3. Shading device: shading device plays a significant role in preventing uncomfortable glare, providing better light distribution and reducing overheating (Manzan & Pinto, 2009); (Yao, 2014); (Englezou & Michael, 2020).
4. Interior materials and painting colors: these factors have a significant influence on the reflectance value of interior surfaces (i.e. walls, ceiling, floor, partitions and furniture) (Brotas & Wilson, 2008), which in turn would affect the internally reflected component of the daylight (MaterialsCouncil, 2012); (Villalba, et al., 2020). Lighting reflectance value is the percentage of visible light reflected by an illuminated surface. It ranges from 0 to 1, as the value 0 represents a material that absorbs 100% of light while the value 1 represents a material that reflects 100%, which are theoretical values that cannot be reached in practice (Negro, et al., 2014).
5. Beds layout: although beds near windows offer a view to outside, patients these beds may suffer from disability glare (Aripin, 2007); (Chavoshani, et al., 2017).

4.4. Daylight, Thermal Comfort and Energy Consumption

As windows' design, position and orientation affect daylight accessibility, they also have considerable influences on the indoor environment in terms of air temperature, which in turn affects the energy needed for heating and cooling. Despite large windows allow the access of more daylight, they may result in excessive heat gain that would lead to a sequential impact on users' thermal comfort as well as heating and cooling loads (Cesari, et al., 2018); (Vanhoutteghem, et al., 2015). Since windows and glazed areas are the lowest-performing parts of the building envelope in controlling heat gain and heat loss (Yao, 2014), it is important to maintain a balance between daylight availability, thermal comfort and energy consumption in the design process (Vanhoutteghem, et al., 2015); (Maleki & Dehghan, 2020). Particularly because building's heating and cooling operations are responsible for the largest share of the energy consumption of buildings, which in turn are responsible for producing excessive emissions of CO_2 (Shamout, 2016). (Jiang, et al., 2012) have shown evidence for that in hospitals, as the largest portion of the consumed energy goes for heating and cooling with a percentage of 48,9%.

Shading devices may be effective solutions for blocking solar radiation to reduce solar gain and overheating (Yao, 2014) as well as preventing the access of direct daylight that may cause visual discomfort such as glare while allowing the entry of reflected daylight to maintain the desired indoor environment in terms of illuminance and air temperature (Manzan & Pinto, 2009); (Englezou & Michael, 2020).

4.5. Visual Comfort and Glare

The European standard EN 12665 defined visual comfort as "a subjective condition of visual well-being induced by the visual environment" which depends on human eye physiology, the amount and distribution of light and the light source (Causone , et al., 2015).

Visual comfort can be achieved by providing an adequate amount of light, good uniformity and reducing glare as much as possible (Bellia, et al., 2008). Visual discomfort is usually expressed as the amount of glare that the human eye is exposed to (Fisekis, et al., 2003). Glare is a physical discomfort that depends on the light distribution (Jakubiec & Reinhart, 2012) and is resulted by exceedingly bright light within the visual field that causes visual discomfort, reduces visibility, or does both (Fisekis, et al., 2003). Based on that, glare can be categorized as discomfort glare, disability glare and veiling glare. Discomfort glare reduces visibility and irritates while disability glare can totally prevent vision. Both types occur due to a visible bright source of light, whereas veiling glare occurs when the bright light is reflected by surfaces (Jakubiec & Reinhart, 2012). Figure 4.2 shows glare types.

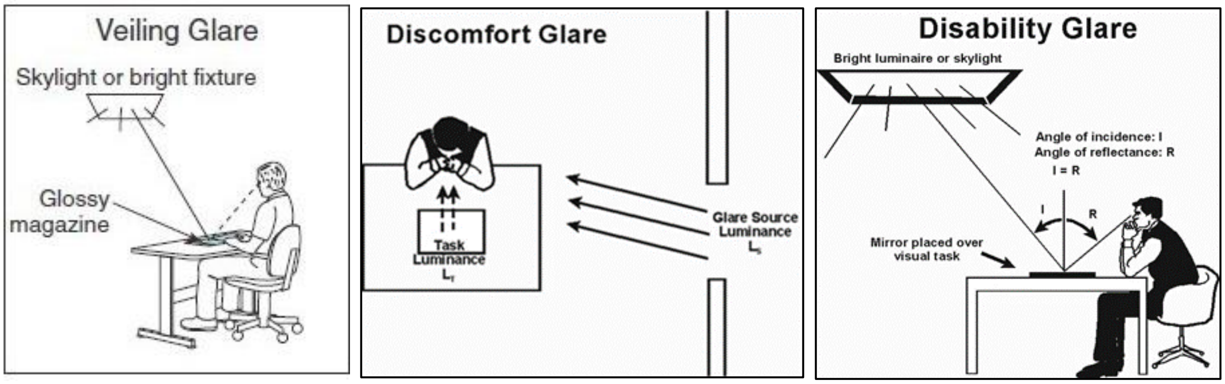


Figure 4.2: Glare types
(Source: http://www.fsec.ucf.edu/en/consumer/buildings/basics/windows/how/glare.htm, https://inspectapedia.com/BestPractices/Window_Shades_Screens.php)

4.6. Conclusion

Daylight in any space consists of sky component, internally reflected component and externally reflected component. It is commonly assessed by measuring the daylight factor, which is the ratio between the indoor and the outdoor illuminance under overcast or uniform sky. Daylight and patient access to view in a healthcare room are influenced by window orientation, window design, the used shading device, the materials and colors of the indoor surfaces and patients' beds' layout. However, these parameters may affect occupants' thermal comfort, heating and cooling loads and visual comfort. Therefore, a balance should be maintained between daylight availability, thermal comfort, energy consumption and visual comfort.

Chapter 5 - METHODOLOGY

5.1. Preface

The study is mainly based on the quantitative method to assess the Palestinian hospitals to investigate whether the ICU designs in Palestine deliver balanced lighting and access to outside views by selecting five Palestinian hospitals as examples. The evaluation is conducted for the ICU of each hospital by making tests and measurements of indoor and outdoor illuminance in different rooms with different orientations and conditions in the ICU of different hospitals. The study optimizes the conditions that achieve the optimal daylighting and access to view for the patient area of the ICU, without increasing the heating and cooling loads through conducting a simulation process using DesignBuilder software. This aims at developing the ideal standards for ICU designs that maintain the optimum lighting in hospitals in Palestine achieved by daylight. This chapter presents the methods used in each phase of the study.

5.2. Palestinian Hospitals Evaluation

The study aims to evaluate the existing conditions of the ICUs in Palestine. To select representative hospitals as case studies, all governmental and non-governmental hospitals licensed by the Palestinian Ministry of Health were classified according to location, the number of ICU beds and the total hospital beds. The collected data based on hospitals' visits, telephone interviews and data obtained from the License & Accreditation Unit of the Ministry of Health, Nablus. The selection criteria are based on a set of conditions that must be met in the hospital, which are the following:

1. The hospital must have an ICU of at least 8 beds.

2. It must be a tertiary hospital that provides a full complement of services.[1]
3. It must be originally designed as a hospital building.
4. It must include at least 150 acute beds.

Each of the selected hospitals was visited 4 - 5 times during the daytime to take measurements of lighting, and record observations of ICU rooms' parameters that affect daylight. Moreover, the floor plan of the ICU of each hospital was analyzed to investigate the impact of its design on daylight quality and the accessibility to the outside views. In addition to conducting personal interviews with some ICU nurses and physicians to evaluate their satisfaction of lighting and access to view conditions.

5.2.1. Daylight Measurement

Field measurements were conducted to the ICUs in the selected hospitals, so that a sample is selected from each group of patient areas that have the same orientation and window design, the average daylight factor was measured in these samples and generalized to the similar patient areas. Selecting this sample from the group was based on the vacant first.

Luxmeter (UT383), shown in Figure 5.1, was used in this study to measure the illumination inside the ICU rooms in addition to the outdoor luminance under overcast sky conditions. The indoor measurements were taken, as recommended (Asdrubali & Desideri, 2019), at a height of 0.85 m in different points in the room in grid shape as shown in Figure 5.2, when the artificial lighting is turned off. These measurements were used to calculate the average daylight factor of

[1] Tertiary hospitals are that provide patients from secondary care-canters a high subspeciality expertise. Also called referral hospitals. (NCBI)

each patient area and compare it with the standard values. The daylight factor DF in each point was calculated using the following equation:

$$DF = 100\% * Ein / Eext \qquad \text{(Kubba, 2012)}$$

Where DF is the daylight factor of a specific point, Ein is the internal illuminance and Eext is the external illuminance under overcast sky conditions.

Figure 5.1: UT383 luxmeter

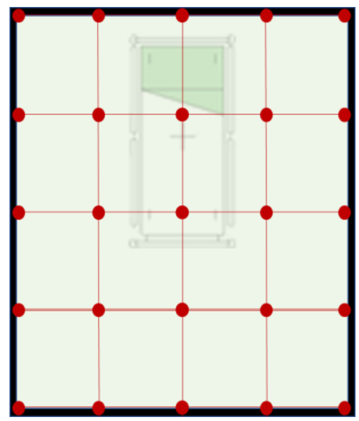


Figure 5.2: The method of dividing the space into points for indoor daylight measurement

As for the average daylight factor in the space, it was calculated as the sum of the daylight factor values of the measured points divided by their number (Asdrubali & Desideri, 2019), as expressed in the equation below

$$\overline{DF} = \frac{\sum_1^n DF}{n}$$

Where $\overline{DF}$ is the average daylight factor in the space, DF is the measured daylight factor in a specific point and n is the number of measured points.

The recommended number of grid points in each side of the area according to EN 12193:2007 and EN 12464-2:2007 is determined by the following equations

$$n_d = d/p$$

$$p = 0.2 \; x \; 5^{log10(d)}$$

Where n_d is the number of points in one dimension, p is the maximum cell area of the grid and d is the longer dimension of the area in meter, while if the ratio of the longer to the shorter side equals 2 or more, then d is the shorter dimension (Iversen, et al., 2013). The maximum spacing of the points can be determined by Table 5.1 below.

Table 5.1: The recommended grid-points number for average daylight factor measurement

Length of the area (d) (m)	Maximum distance between points (p) (m)	Minimum number of points
0.4	0.15	3
0.6	0.20	3
1.0	0.20	5
2.0	0.30	6
5.0	0.60	8
10.0	1.00	10
25.0	2.00	12
50.0	3.00	17
100.0	5.00	30

Source: (Iversen, et al., 2013)

5.2.2. Interviews

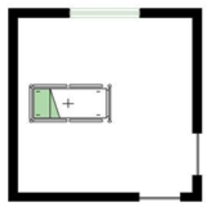
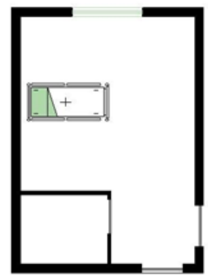
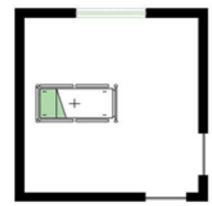
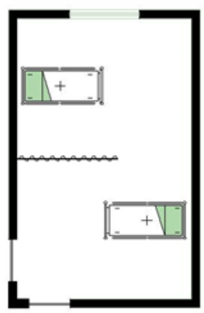
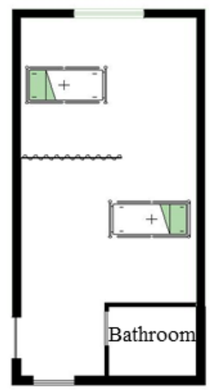
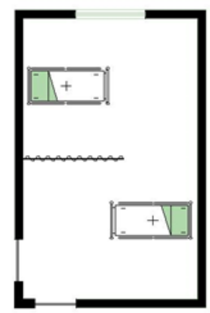
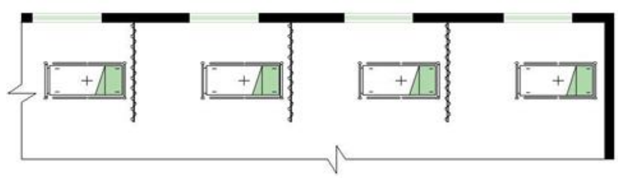
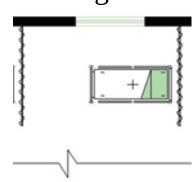
Open-ended interviews were recorded with doctors and nurses of the ICUs of the studied hospitals to investigate patients and medical staff complaints of lighting quality achieved by daylight and access to outside views, evaluate their responses of daylight quality and its impact on the incidence of delirium among patients and determine their requirements of the design of ICU. Interviews also targeted the engineers of the engineering departments of the studied hospitals and who belongs to the ministry of health of Palestine as well, to investigate the ICU design details and conditions of each hospital. The interviews questions are in Appendix B.

5.3. Optimization of the Parameters Affecting Daylight

DesignBuilder software- Version 6.0.1 019 was used as a simulation tool to optimize the parameters affecting daylight in terms of daylight, heating and cooling loads. DesignBuilder is based on EnergyPlus simulation engine to assess building performance in terms of lighting, ventilation, heating and cooling loads. Radiance illuminance simulations are used in DesignBuilder to calculate daylight factor, which based on calculating the indoor illumination levels on the working plane using sky distributions and static external lighting. This calculations allow light transmittance and blocking by different types of materials (altensis, 2015).

Three models were used in the optimization process to further investigate the impact of different parameters on daylighting and to determine the conditions that achieve the optimal daylighting and the minimal energy consumption for heating and cooling as well. The three models represent a single/isolated ICU room, a two-bed- ICU room and a patient area within a multibed ICU ward, which are the common cases of ICU patients' areas in Palestine, the cases are in Table 5.2.

Table 5.2: Simulation models used in the study

Study cases	Cases		Simulation model
Single/isolated ICU room	Single/Isolated room without a bathroom 	Single/Isolated room with a bathroom 	25m2 square-room of a 3m height 
Two beds- ICU ward	Two bed- ICU room without a bathroom 	Two bed- ICU room with a bathroom 	(5 * 8) m2 rectangle-room of a 3m height 
Patient zone within a multibed ICU ward			(4,3* 4,7) m2 rectangle-room of a 3m height 

The models' dimensions were based on the standards of the ICU design mentioned in Chapter 3, Section 3.2. While beds' layout was arranged in a way that achieves access to view. The beds' layout in the two bed-ICU room was inverted from an ICU design of Deilmann architect (Neufert & Neufert, 2012), since this layout can provide access to view for patients, while, in the case of more than 2 beds, the wall side layout becomes more appropriate, to provide access to view as well as privacy. Figures 5.3 and 5.4 show the classification of beds' layout cases and the selected ones. The studied models, that have a single window on the external wall of each model, were modeled and simulated using DesignBuilder software. The optimization process targeted orientation, window to wall ratio, light reflectance value, window lintel level height and shading device level height and depth.

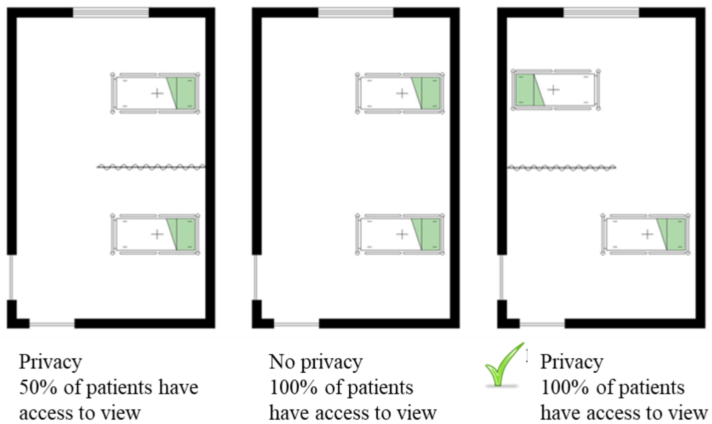


Figure 5.3: Classification of beds' layout cases of the 2 bed-room according to privacy and access to view provision. The selected case is on the right.

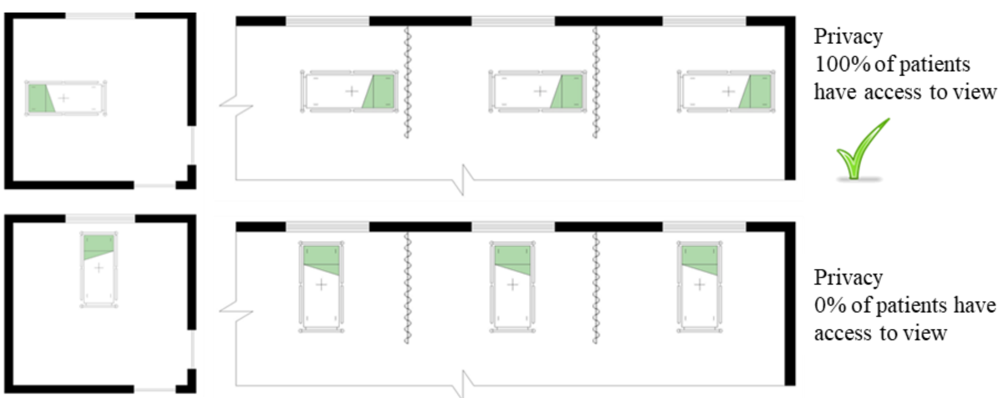


Figure 5.4: Classification of the beds' layout cases of the ICU single/isolated room and patient zone within a multibed ICU-ward according to privacy and access to view provision. The selected cases are above.

Depending on the average annual solar path in Jerusalem climate, the simulation process focused on determining the average daylight factor and the annual heating and cooling loads of the room in parametric conditions. The used optimization equation is:

$$Min\ f(x) = E - \overline{DF}, \qquad subject\ to\ \overline{DF} \geq 3$$

Where E is the annual heating and cooling loads and $\overline{DF}$ is the average daylight factor in the space, which must not be below 3. Annual energy consumption changes of 10 KWH or less was assumed negligible in selecting the optimal values of the studied parameters. The uniformity ratio was tested in the parameter of light reflectance value and neglected in other parameters.

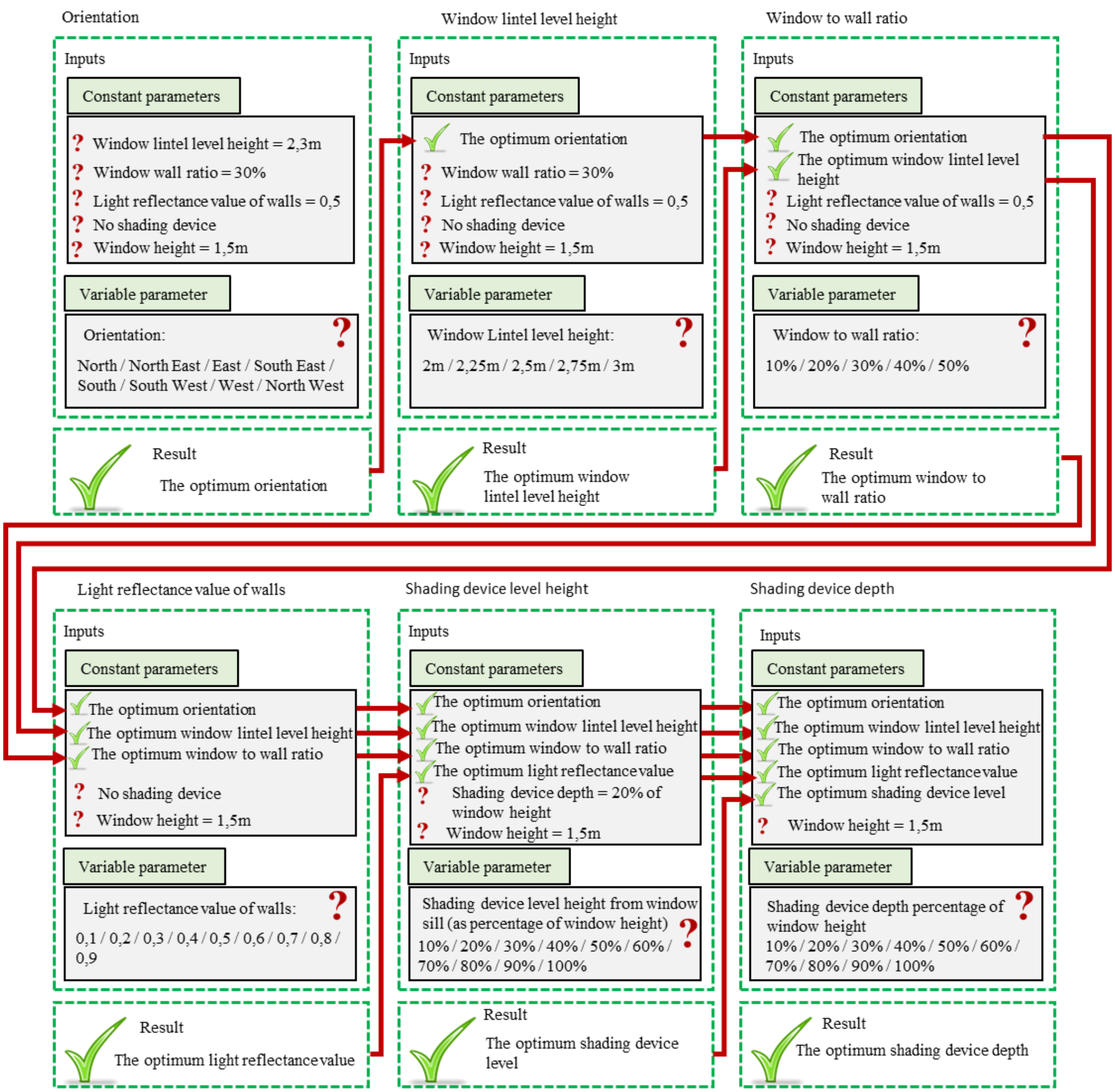


Figure 5.5: The steps of the optimization process

The optimization process was conducted by accumulative and successive steps, such that, the result of each step of parameter optimizing was used as a simulation input for steps next to it. For example, the resulted value of optimizing window lintel level height was used in optimizing window to wall ratio and all next parameters, then the results of the window to wall ratio as well as window lintel level height were used as inputs in optimizing light reflectance value and shading devices' level and depth, and so on. In this way, the final result would be the optimum values of all parameters together, taking into account the effect of each parameter on the other, as shown in Figure 5.5.

The results of the annual heating and cooling loads were expressed by the amount of KWHs of all cases. However, the results of the single ICU room were expressed by MJ (in addition to KWH) to clarify the relationship between the daylight factor and the heating and cooling loads in a single diagram.

5.3.1. Simulation Inputs

All simulation trials were conducted while the HVAC system is turned on: natural gas was used for heating and electricity from grid for cooling. Natural ventilation was deactivated, while mechanical ventilation, domestic hot water were active. Table 5.3 shows the constant input parameters used in the optimization process.

Table 5.3: Simulation constant parameters

Window Glass Type	Double glass of Generic clear 3mm (for each layer) and 13mm air between the two layers.
U-value of window	2.116 W/m^2.K
Natural Ventilation	Inactive
Mechanical Ventilation	Active
Domestic Hot Water (DHW)	Active
HVAC System	Active
Heating system	Natural gas
Heating Set Point	22 ℃
Cooling system	Electricity from the grid
Cooling Set Point	24 ℃
Air Infiltration	0.7 ac/h
U-value of the walls	0.350 W/m^2.K
U-value of the slab	0.250 W/m^2.K

5.4. Enhancement of the Studied ICUs

The optimization results were used to modify the patients' areas of the ICUs in the studied hospitals to be enhanced in terms of daylight and patients' access to view. Patients' areas were enlarged to comply with the ICU functional requirements. Furthermore, a comparison between the original design and the modified of each ICU was conducted to investigate the enhancement potential of the current ICUs in Palestine using the optimization results.

Chapter 6 - DATA COLLECTION, RESULTS AND DISCUSSION

6.1. Preface

The data obtained from the Palestinian hospitals' evaluation and the optimization process are presented and discussed in this chapter. Moreover, the results of the optimization process are used at the end of this chapter to modify the ICU designs in the Palestinian hospitals to be enhanced in terms of daylight and access to view. [2]

6.2. Palestinian Hospital Evaluation

6.2.1. Hospital Classification

Hospitals' classification of the governmental and non-governmental hospitals licensed by the Palestinian Ministry of Health according to location, number of ICU beds and the total hospital beds are shown in Table 6.1. The hospitals that achieve the selection conditions of a minimum number of hospital beds and ICU beds of 150 and 8 respectively are Alahli Hospital and Alia Hospital in Hebron (serve the southern governates), Istishari Arab Hospital and Palestine Medical Complex (PMC) in Ramallah & Al-Bireh (serve the central governates) and Rafidia Hospital and An-Najah National University Hospital in Nablus (serve the northern governate). All those hospitals are tertiary and originally designed as hospitals. Alahli, Istishari Arab and An-Najah National University hospitals are non-governmental, while the others are governmental; which is a strong point -besides the diversity of the geographical locations of the hospitals- in representing all cases of hospitals in Palestine. However, the study did not include Rafidia Hospital, due to the inability to access the necessary data according to the decision of the hospital administration not to share information for research purposes. All the selected hospitals are located on high-level

[2] The results of the daylight measurements are in Appendix A.

lands relative to the surroundings and not surrounded by high buildings. Therefore, the impact of the surrounding buildings on the internal lighting achieved by daylight was neglected.

Table 6.1: Hospitals' classification of the hospitals licensed by the Palestinian Ministry of Health according to location, number of ICU beds and the total hospital bed

No.	Governate	Hospital name	No. of hospital beds	No. of ICU beds	No.	Governate	Hospital name	No. of hospital beds	No. of ICU beds
1	Hebron	Al Ahli	250	16	23	Ramallah & Al Bireh	Palestine Medical Complex (PMC)	279	23
2		Al Meizan	70	0	24		Palestine Red Crescent Society- Al Bireh	69	1
3		Bani Na'em	10	0	25		Walid El Nazer	10	0
4		Hebron (Alia)	252	10	26	Nablus	Al Amal for Rehabilitation	10	0
5		Mohammad Ali Al Mohtaseb	30	0	27		Al Itihad	51	4
6		Naser- Yatta	14	0	28		Al Watani	94	7
7		Palestine Red Crescent Society- Hebron	53	0	29		An-Najah National University	151	11
8		Yatta (Abu Al Hassan Al Kassem)	74	4	30		Nablus Specialized	54	11
9	Bethlehem	Beit Jala (Al Hussein)	131	5	31		Rafidia	201	10
10		Al Dibs	10	0	32		Specialized Arab	101	8
11		Al Yamamah	24	4	33		St. Luke's	46	4
12		Shepherds Field	15	0	34	Tulkarm	Al Zakah	42	5
13		Holy Family	63	0	35		Palestine Red Crescent Society- Tulkarm	10	0
14		Arab Society	99	5	36		Thabit Thabit	126	7
15		Caritas (Paediatric)	74	0	37	Jenin	Jenin (Khaleel Sulaiman)	207	5
16		Health Work Committees	13	0	38		Al Razi	40	7
17	Ramallah & Al Bireh	Al Mustaqbal	28	1	39		Al Amal	18	3
18		Arab Care Medical Services	37	3	40		Shifa	21	1
19		H Clinic	40	6	41	Qalqiliya	Qalqiliya (Darweesh Nazal	62	3
20		Hugo Chavez	38	6	42	Salfit	Yasser Arafat	50	3
21		Istishari Arab	170	10	43	Jericho & Al Aghwar	Jericho	54	3
22		Khaled Tarifi	14	0	44	Tubas	Tubas Turkish	45	3

6.2.2. Alahli Hospital

Al-Ahli Hospital was built in 1988 on an area of approximately 30,000 square meters. It operates with a capacity of 250 beds, which can be easily raised to 500 beds in emergency cases. Currently, 600 employees work in Al-Ahli Hospital in all its departments. The hospital annually deals with more than 160,000 patients, including more than 24,000 cases of admission into the different departments (Ahli-Hospital, 2020).

The ICU of Alahli hospital was established in 1997 (Silmi, 2020) and renovated and expanded in 2017 (Sultan, 2020). It is located on the first floor and oriented toward the South-East as shown in Figure 6.1. The ICU design is generally centralized, with a central workstation that observes 8 beds around it, while the other part, which is for isolated patients is decentralized and contains another 8 beds as shown in Figure 6.2. The height of patient rooms in the ICU is uneven and ranges from 230 cm to 250 cm, due to the difference in the false ceiling level. Pastel green is the main colour of the ICU walls, while white is used for the ceiling and the curtains between patients.

In the interview recorded on 3rd/February/2020 with S.S., a civil engineer in the maintenance department, the ICU expansion was not under the supervision of specialized architects, and rather it was an implementation of the request of the hospital's administrative director. Despite that, the license was given by the Ministry of Health as it meets the requirements in terms of medical services (Sultan, 2020).

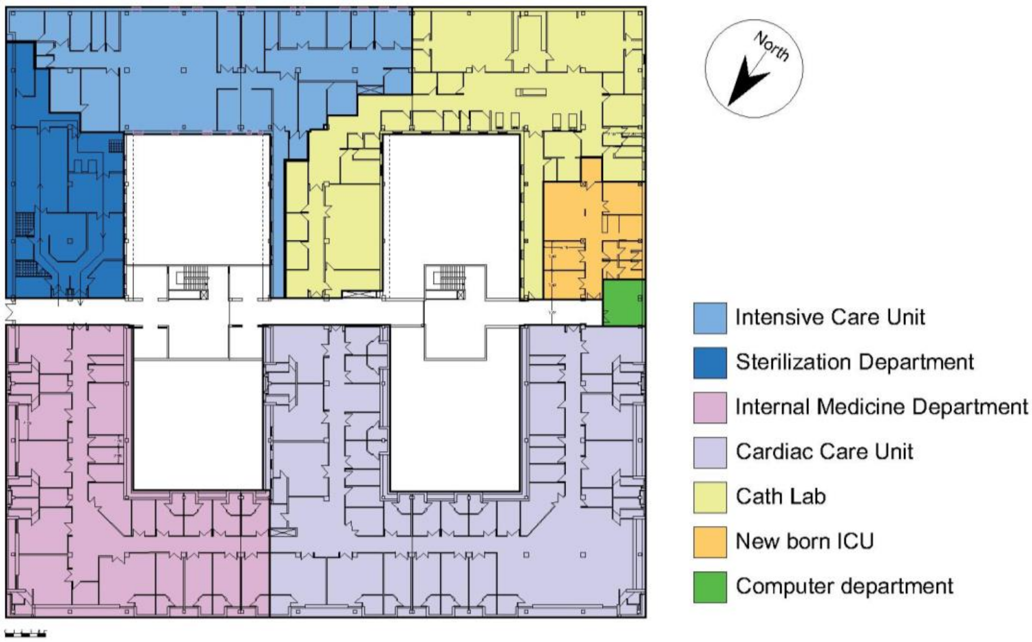


Figure 6.1: The first-floor plan of Al-Ahli hospital.

Source: The engineering department of Alahli Hospital (edited by author).

Figure 6.2: The plan of the ICU of Al-Ahli hospital

Source: The engineering department of Alahli Hospital (edited by author).

Family visits are restricted and allowed only for 10 minutes 3 times a day: at 7 AM, 11 AM and 4 PM (Abu-Arish, 2020). Furthermore, family support areas are not taken into account in Alahli ICU design, with no facilities for them to sleep or even sit beside the patient. The administration room, the conference room and offices as well as the laboratory and the pharmacy are separated from the ICU, with easy access to them. Whereas, bedrooms for on-call doctors and nurses with related utilities are within the ICU.

6.2.2.1. Lighting Quality

Most windows of the ICU are oriented toward the south-east, where few windows are oriented toward the opposite direction into a courtyard. Windows, which need to be closed all the time for sterilization purposes, are relatively small, with rough glass texture and a high sill level. Therefore, the daylight quality is considered poor, and the artificial lights need to be turned on all day. Furthermore, the rough-glass windows, the high sill level and the beds' layout, which are directed toward the interior, make it impossible for patients and medical staff to see the outside views. This is in line with nurses' complaints that they cannot differentiate between day and night, and patients repeated questions about time. Windows' height ranges from 40 cm to 55 cm with around 170 cm sill height in all patients' rooms except 4 windows in 3 rooms for isolated patients, which are 104 cm height and 118cm sill height. The two types of windows used in the ICU of Alahli Hospital are shown in Figure 6.3. No glare was observed and no patients complained about it reported by nurses (Abu-Arish, 2020).

According to the interview recorded on 3rd/February/2020 with M.J., the electrical engineer of Alahli hospital, there are no dedicated lighting units for the night, while lighting can be diminished by turning off the lighting units over patients and keeping the other units (Aljubeh, 2020).

Figure 6.3: ICU single rooms in Alahli Hospital with a turned-off artificial lighting.[3]

To assess the lighting quality achieved by daylight, the average daylight factor was measured in three patient areas shown in Figure 6.4. The measured daylight factor of each patient area and the average illuminance as well as the characteristics of each area are in Table 6.2.

Figure 6.4: ICU patient areas in Alahli Hospital where the average daylight factor was measured.

Source: The engineering department of Alahli Hospital (edited by author).

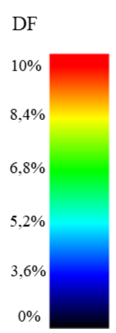
[3] The photos were taken by the author on 3rd/February/2020 at 9:00 AM.

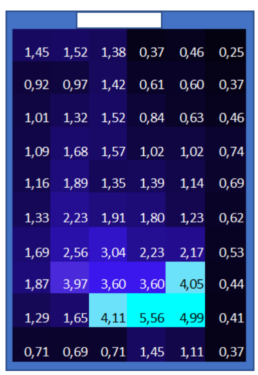
The values of the average daylight factor of all patient areas are below the required value. This probably is due to the low values of the window to wall ratio and the high window level. At the best, the average illuminance reaches 167 lux, while in most patient areas, it doesn't exceed 16,8 lux. The detailed measurement results are in Appendix A.

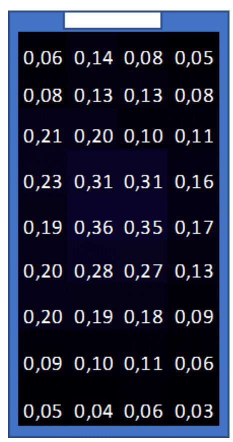
Table 6.2: The field measurements of the selected patient areas of the ICU in Alahli Hospital

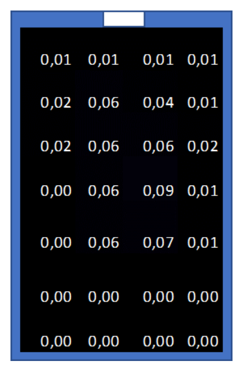
Patient area number	1	2	3
Area type	Isolation room	Isolation room	Patient area within a two-bed room
Orientation	South-East	South-East	North-west
Widow to wall ratio	17.8%	7,2%	3,6%
Window lintel level height	222 cm	215 cm	215 cm
Window sill level height	118 cm	170 cm	170 cm
Average daylight factor	1,55%	0,15%	0,02%

Measured daylight factor map









Average illuminance	167 lux	16,8 lux	2,4 lux
Access to view	No access to view	No access to view	No access to view
Measurements were taken under overcast sky conditions during the morning from 9A M to 10 AM in 8/4/2020.			

6.2.2.2. The Incidence of Delirium

According to the interview with A.B., the head doctor of the ICU of Alahli hospital on 3rd/February/2020, Delirium is very common for patients in the ICU of Alahli Hospital, and they are treated according to general guidelines; if it is confirmed that there are no health causes for the disease, delirium is attributed to the ICU environment, especially to the lack of daylight and access to view. However, because the ICU design is not prepared to deal with these cases, patients are treated with only medication, apart from providing an appropriate environment. Furthermore, in some cases, patients may have an early discharge to ensure that their health will not get worse as a result of delirium (Al-Bayaa, 2020). It is worth to mention that on one occasion, the medical staff had to transfer the bed of a delirious patient in addition to the necessary equipment such as the ventilator to the hospital yard, to improve his health condition (Abu-Hanieh, 2020). Moreover, many patients have sleep problems, and cannot distinguish the time. This is one of the most common complaints of patients, as expressed by Z.A., a nurse in the ICU (Abu-Arish, 2020).

The head doctor of the ICU emphasizes that improving the ICU environment by increasing daylight, enabling patients to see the outside views, creating suitable night conditions for sleep and improving family involvement will probably reduce the occurrence of delirium (Al-Bayaa, 2020).

6.2.3. Alia Governmental Hospital

Alia Governmental hospital is a governmental hospital in Hebron city that was built in 1957. It is over-occupied with an occupancy rate of 155%, which is the highest among the Palestinian hospitals. It contains 239 beds. The hospital staff consists of 508 employees in various fields (GSQD, 2018).

The ICU was first established when the hospital was built in 1957, then a new section was built to accommodate more services in 2014 and officially opened in 2018. The new unit was designed by the department of engineering and construction that belongs to the Ministry of Health (Atawneh, 2020). The unit now contains 19 beds. 9 of them are out of service, due to the shortage of medical staff (Qudaimat, 2020). among the 19 beds, there are 4 beds in isolated rooms, where the partitions are made of transparent glass. One of them is also out of service for the same reason. The ICU is located on the third floor with a height of 291cm. Its design is centralized and the colours of the interior walls, the ceiling and the curtains are light beige, white and pastel blue respectively. The ICU deals with all ages even new-born children; as there is no specified unit for them. The ICU floor plan is shown in Figure 6.5 and 6.6.

The design does not support family visits; as there are no spaces for them to sit or sleep in the patient areas, or even outside the unit. Family visits are restricted and allowed only for two minutes at 11 AM, 4 PM and 7 PM (Asafrah, 2020).

The operation rooms, the surgery department and the sterilization Department are placed next to the ICU on the same floor, with easy access to them. Therefore, any emergency surgical intervention can be done quickly outside the department. Cath lab is located to the south from the ICU, with a subsidiary door for emergency transfer of Cath patients to the ICU or the Open-Heart Theatre outside the unit by using the path shown in Figure 6.5.

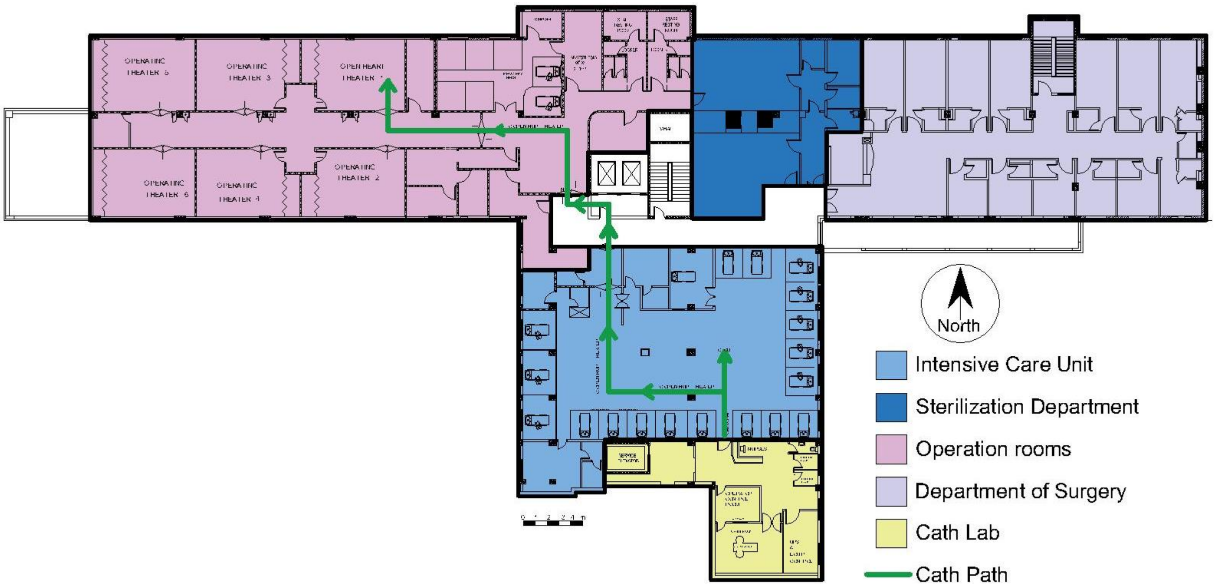


Figure 6.5: The third-floor plan of Alia Governmental Hospital

Source: The engineering department of Alia Governmental Hospital (edited by author).

Figure 6.6: The plan of the ICU of Alia Governmental Hospital

Source: The engineering department of Alia Governmental Hospital (edited by author).

6.2.3.1. Lighting Quality

Beds layout mainly takes the U-shape; therefore, the patients' area can be divided into two main areas in terms of daylight exposure: the first part includes beds that are placed along the western and the eastern walls, which mainly depends on daylight for lightening, because of the presence of relatively large windows. However, glare was observed in this part, which may probably be due to the low-angle sun rays in the west and east directions. The second includes beds along the southern and the northern walls, which are windowless. Therefore, this part depends completely on artificial lighting.

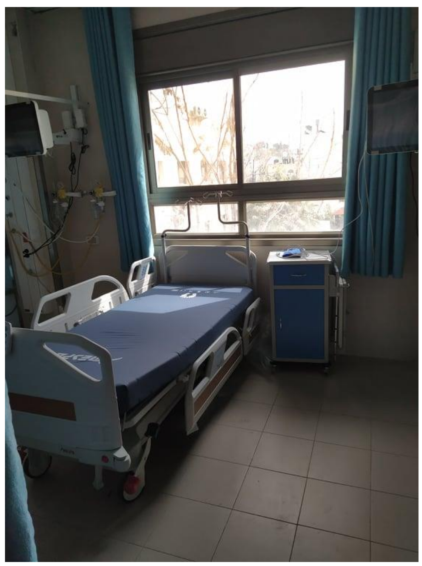


Figure 6.7: ICU patient area with a turned-off artificial lights in Alia Governmental Hospital. [4]

Windows are not tinted or roughed and each one has a sill height of 1 meter and consists of two panels, the higher panel is openable and 1meter high, while the lower is fixed and 0.3-meter-high as shown in Figure 6.7. However, windows need to be closed all the time for sterilization purposes.

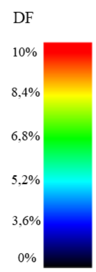
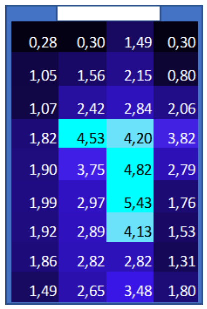
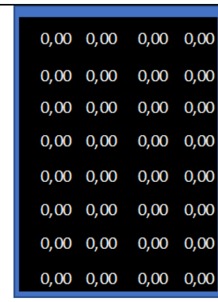
[4] The photo was taken by the author on 19th/February/2020 at 9:30 AM.

In the interview recorded on 23rd/February/2020 with M.Q., the head doctor of the ICU, conscious patients prefer beds beside windows and many of them who are on the southern side ask to be moved to one of the other sides to be beside windows (Qudaimat, 2020).

Patients have no access to the outside view, even those in the western and the eastern sides, because of the beds' layout that makes patients face the interior. Furthermore, it was observed that glare occurs in the patients' areas near windows. The average daylight factor was measured in two patient areas as shown in Figure 6.8. the results in Table 6.3 show that the average daylight factor is below the required value in room 1 despite the window to wall ratio reaches 26%. Moreover, in some patient areas, particularly the southern ones, the illuminance equals zero. The detailed measurement results are in Appendix A.

Figure 6.8: ICU patient areas in Alia Governmental Hospital where the average daylight factor was measured
Source: The engineering department of Alia Governmental Hospital (edited by author).

Table 6.3: The field measurements of the selected patient areas of the ICU in Alia Governmental Hospital

Patient area number	1	2
Area type	Patient area within an ICU ward	Patient area within an ICU ward
Orientation	East	South
Widow to wall ratio	26%	0
Window lintel level height	230 cm	---
Window sill level height	100 cm	---
Average daylight factor	2,36%	0%
Measured daylight factor map 		
Average illuminance	255 lux	0 lux
Access to view	No access to view	No access to view
Measurements were taken under overcast sky conditions during the morning from 10:30 AM to 11:30 AM in 8/4/2020.		

6.2.3.2. The Incidence of Delirium

In the interview recorded on 19th/February/2020 with A.A., a nurse in the ICU of Alia Governmental Hospital, ICU delirium is a considerably common condition for patients who are conscious and may occur within few days of their admission (Asafrah, 2020). Those patients are given medications to treat the delirium, and in some cases, they are transferred from the ICU, if their health condition allows that (Qudaimat, 2020).

6.2.4. Palestine Medical Complex

Figure 6.9: The first floor plan of Palestine Medical Complex

Source: The engineering department of Palestine Medical Complex (edited by author).

Palestine Medical Complex is a governmental hospital in Ramallah. It includes 279 beds spread over four wings: Ramallah's sons' wing, paediatric wing, heart and specialized surgeries wing and emergency wing (PHIC, 2019). The ICU in Palestine Medical complex is on the first floor and includes 23 beds, 11 of them are in an open plan ward, while the others are in single rooms that can be used for isolation. Eleven of those single rooms, that were designed as an expansion to the open plan ward, are under construction and are still not used at the moment. The ICU height is 2,9 m and its design is mainly centralized with golden curtains between beds, pink and off-white painted walls, and white ceiling tiles. Figure 6.9 shows the first-floor plan of Palestine Medical Complex where the ICU is located.

According to the interview recorded on 29th/July/2020 with A.G., the electrical engineer of the Palestine Medical Complex, the design of the ICU expansion was not carried out by a group of specialized architects (Ghawadreh, 2020). Bedrooms, offices and related utilities of the ICU staff, as well as stores, are within the ICU, while the laboratory and the pharmacy are separated from the unit with easy access to them. The current ICU as well as the expansion are shown in Figure 4.10.

Figure 6.10: The plan of the ICU of Palestine Medical Complex

Source: The engineering department of Palestine Medical Complex (edited by author).

6.2.4.1. Lighting Quality

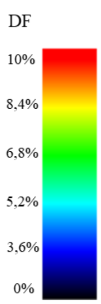
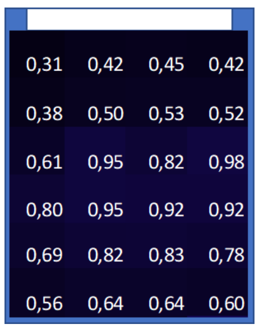
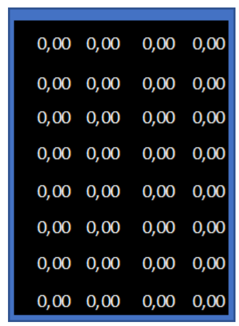
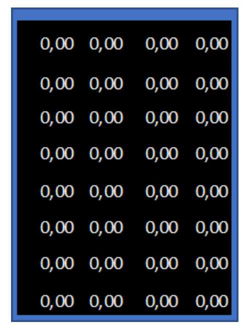
The current ICU of the Palestine Medical Complex is completely dependent on artificial lighting, as there are no windows in the unit, except 2 small-size and high-level windows with curtains that are hard to reach; therefore, they are always closed. Therefore, nothing can be seen if the artificial lights are turned off. Moreover, there is no access to the outside views by patients or medical staff due to the absence of windows.

In the interview recorded with E.T., the head nurse of the ICU of Palestine Medical Complex, many complaints are heard from patients and staff due to the lack of natural lighting, and many inquiries about time are raised, they even cannot differentiate between day and night (Tumeh, 2020).

Daylight measurements of the areas presented in Figure 6.11 confirm the fact that the design of the current unit does not consider the natural light, as the general illuminance recorded in most patients' areas of the unit, when artificial lights are turned off, equals 0 as shown in Table 6.4. On the other hand, the illuminance of the ICU expansion seems to be better than the current one, because of the presence of windows. The detailed measurement results are in Appendix A.

Figure 6.11: ICU patient areas in Palestine Medical Complex where the average daylight factor was measured
Source: The engineering department of Palestine Medical Complex (edited by author).

Table 6.4: The field measurements of the selected patient areas of the ICU in Palestine Medical Complex

Patient area number	1	2	3
Area type	Patient area within an ICU ward	Patient area within an ICU ward	Patient area within an ICU ward
Orientation	North	West	North
Widow to wall ratio	16%	0	0
Window lintel level height	290 cm	---	---
Window sill level height	240 cm	---	---
Average daylight factor	0,67%	0%	0%
Measured daylight factor map 			
Average illuminance	79,5 lux	0 lux	0 lux
Access to view	No access to view	No access to view	No access to view
Measurements were taken under overcast sky conditions during the morning from 9:00 AM to 10 AM in 1/9/2020.			

6.2.4.2. The Incidence of Delirium

According to the head nurse, many ICU patients have sleep problems and depression as well as delirium, which they diagnose by examining the patient's perception of time, place and people, while the plan of treatment is limited to administering medication, regardless of the ICU environment or the communication with the external nature, since the design does not support that.

6.2.5. Istishari Arab Hospital

Istishari Arab Hospital is one of the largest private hospitals in Palestine, Ramallah. It includes 170 beds and provides comprehensive and varied medical services. The ICU was established as a part of the hospital when it opened in 2016 (IAH, 2017). It is located on the first floor next to the operations department, the obstetrics department and the newborn ICU as shown in Figure 6.12.

Figure 6.12: The first floor plan of Istishari Arab Hospital

Source: The engineering department of Istishari Arab Hospital (edited by author).

The ICU contains 9 beds in an open plan hall and one in a single room used for isolation. Its design is centralized, as a central nurse station observes all the ICU beds around it. In addition to the Patient beds and utilities, the ICU includes only a small-area store as well as a waiting room, while the medical staff's rooms, offices and utilities are separated from the unit, this can be noticed from the floor plan in Figure 6.13.

The ICU beds are divided by rough-surface glass partitions, while curtains are used in front of each bed to separate the patient areas from the nurse station. The internal height is 2,8m and walls and ceiling are painted white, while floor finishing is blue as shown in Figure 6.14.

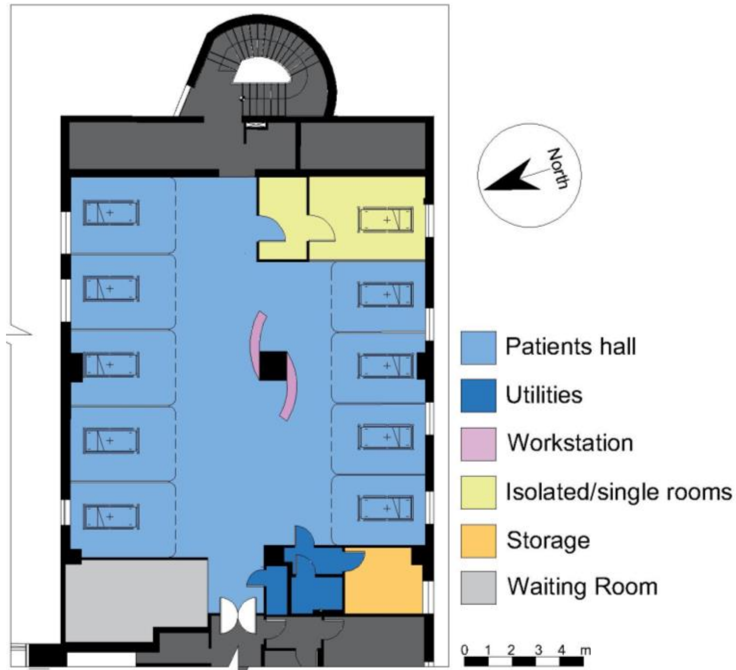


Figure 6.13: The plan of the ICU of Istishari Arab Hospital

Source: The engineering department of Istishari Arab Hospital (edited by author).

Figure 6.14: ICU patient area with a turned-off artificial lights in Istishari Arab Hospital. [5]

[5] The photos were taken by the author on 29th/July/2020 at 1:00 PM.

6.1.5.1. Lighting Quality

The ICU windows of the Istishari Arab Hospital are tinted and relatively large, with two different types: the first is oriented toward the south and is 144 cm high with a sill height of 88cm, and the second is oriented toward the north and has a height of 180 cm and a sill height of 63 cm. It was observed that the ICU lightening depends mainly on natural light in most patients' areas during the daytime, while artificial lights are used to lighten the nurse station.

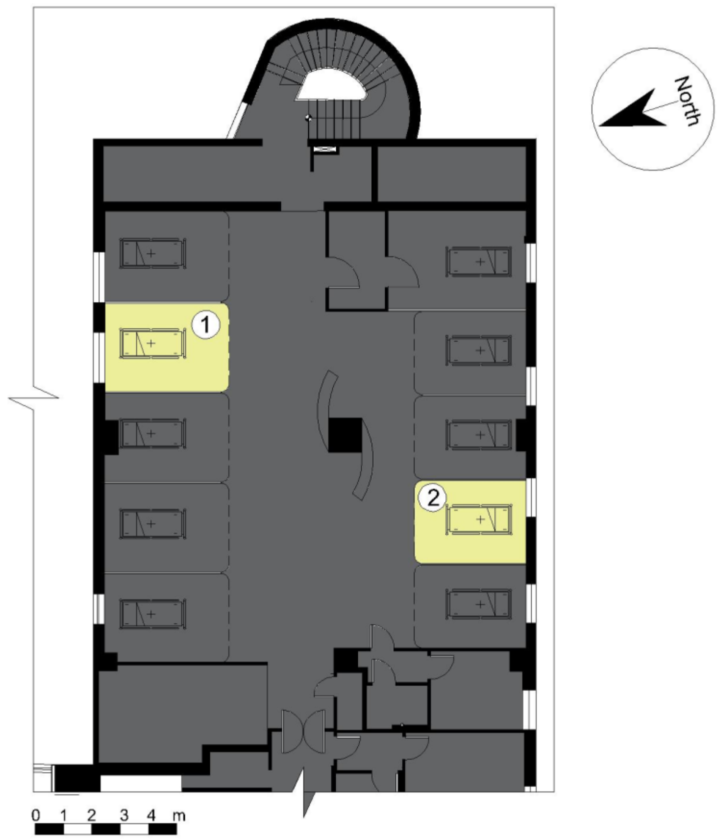


Figure 6.15: ICU patient areas in Istishari Arab Hospital where the average daylight factor was measured.

Source: The engineering department of Istishari Arab Hospital (edited by author).

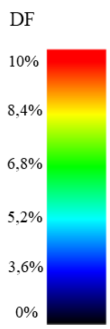
Daylight measurements targeted two patients' areas with different window types as shown in Figure 6.15. While the results are in Table 6.3.

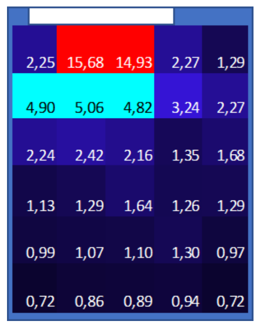
The southern patients' areas were found to have an average daylight factor of more than 3%, which is acceptable. However, despite the window to wall ratio of the northern areas is more than the southern, daylight requirement is not achieved at patients' areas there.

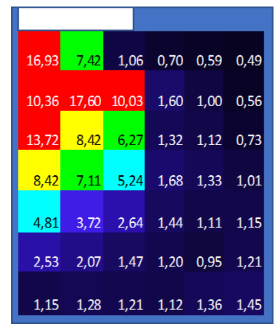
There is a panoramic natural view that can be seen from the windows, but the beds' layout makes it difficult for patients to view the landscapes without getting off the beds. The detailed measurement results are in Appendix A.

Table 6.5: The field measurements of the selected patient areas of the ICU in Istishari Arab Hospital

Patient area number	1	2
Area type	Patient area within an ICU ward	Patient area within an ICU ward
Orientation	North	South
Widow to wall ratio	36%	24%
Window lintel level height	243 cm	232 cm
Window sill level height	63 cm	88 cm
Average daylight factor	2,76%	3,73%
Measured daylight factor map		







Average illuminance	327 lux	443 lux
Access to view	No access to view	No access to view
Measurements were taken under overcast sky conditions during the morning from 8:00 AM to 8:30 AM in 2/9/2020.		

6.2.5.2. The Incidence of Delirium

In the interview recorded on 29th/July/2020: R.H, the head nurse of the ICU in Istishari Arab Hospital emphasized that it is very common for conscious ICU patients to develop delirium. Those delirious patients are treated only by medication (Halaiqa, 2020). Moreover, according to N.M., a nurse in the unit, patients who are in windowless areas usually complain and ask about time and many of them develop delirium, particularly those who have a long length of stay in the unit (Mansur, 2020).

6.1.6. An-Najah National University Hospital

An-Najah Hospital is a teaching hospital affiliated with An-Najah National University in Nablus, which was established in 2013. The hospital is one of the largest hospitals in Palestine, which includes 151 beds. It contains a newborn ICU as well as two adult ICUs: the surgical ICU and the medical ICU. The surgical ICU is located on the second floor next to the newborn ICU, a surgery department, a vascular surgery department, and operation rooms as shown in Figure 6.16. The surgical ICU contains 6 ICU beds; four of them in an open plan ward, and the others in a two-bed room for isolation as shown in Figure 6.17.

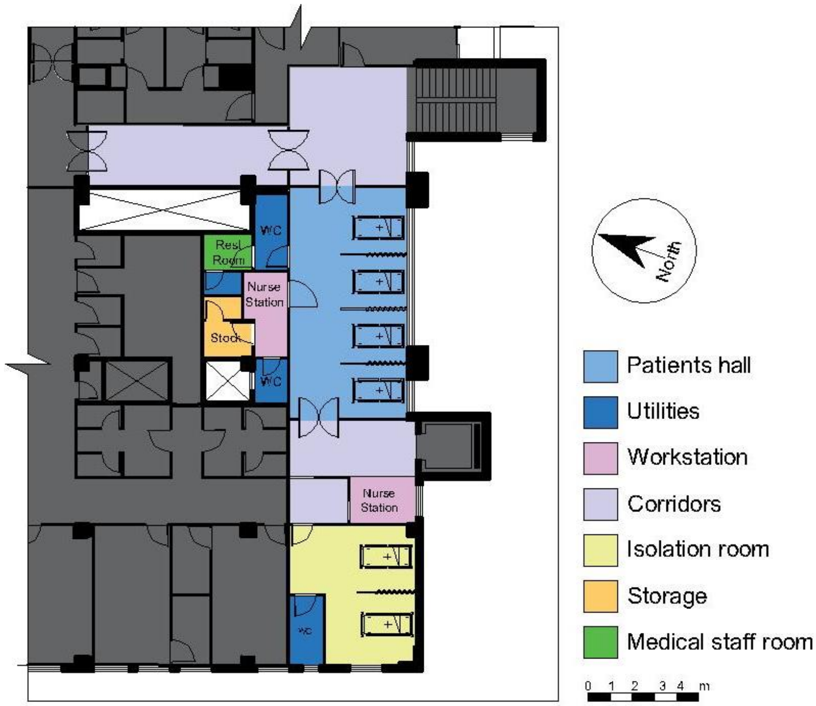


Figure 6.16: The plan of the surgical ICU of An-Najah National University Hospital.

Source: The engineering department of An-Najah National University (edited by author).

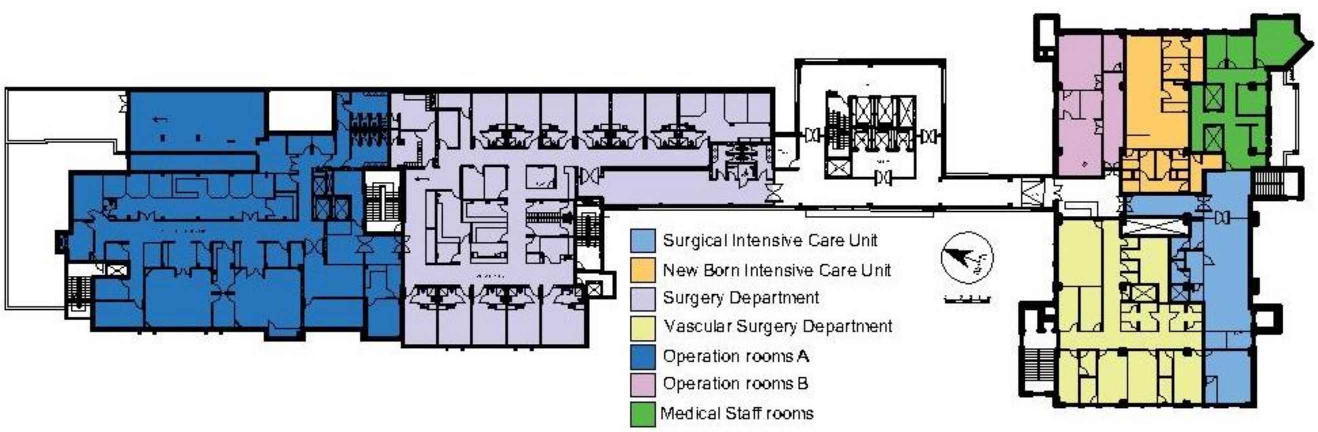


Figure 6.17: The second floor plan of An-Najah National University Hospital

Source: The engineering department of An-Najah National University (edited by author).

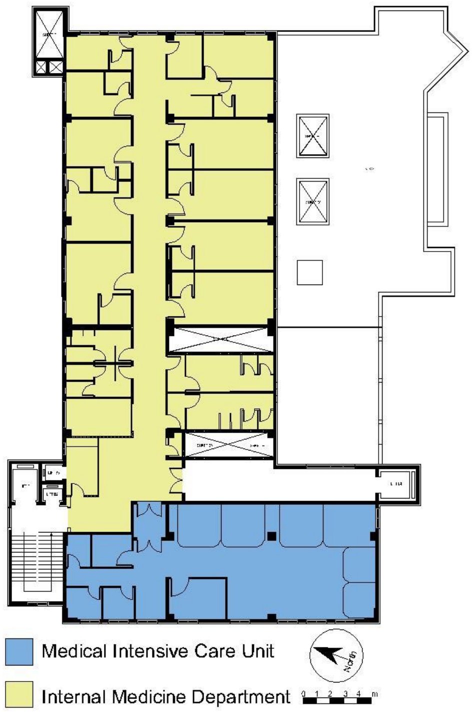


Figure 6.18: The fourth floor plan of An-Najah National University Hospital.

Source: The engineering department of An-Najah National University (edited by author).

Figure 6.19: A patient area in the surgical ICU of An-Najah National University Hospital [6]

Whereas, the medical ICU is located on the fourth floor next to the internal medicine department as shown in Figure 6.18. It includes 5 beds, three of them are in an open plan ward, while the others in isolation rooms, as shown in Figure 6.19. Blue curtains are used to separate beds in the surgical ICU as shown in Figure 6.20, while fixed partitions maid from rough glass are used for that in the medical ICU, and both of them have a white ceiling and white walls. Blue and beige are the used paint colors for the surgical ICU and the medical ICU respectively.

[6] The photo was taken by Ameer Reesheh in 23rd/September/2020 at 10:00 AM.

6.2.6.1. Lighting Quality

The surgical ICU has relatively large windows of a height of 172 cm and a lintel height of 198 cm. Windows are oriented toward the south except for a window in the isolation room, which is oriented toward the west.

Beds in the open plan ward of the surgical ICU face the interior. Therefore, patients cannot access the external view in laying down or sitting positions.

On the other hand, windows of the medical ICU, which are oriented toward the west, are smaller with a height of 125 cm and a lintel height of 218 cm.

Figure 6.21: ICU patient areas in An-Najah National University Hospital where the average daylight factor was measured.

Source: The engineering department of An-Najah National University (edited by author).

Figure 6.20: The plan of the medical ICU of An-Najah National University Hospital.

Source: The engineering department of An-Najah National University (edited by author).

Beds of the open plan area are far from windows, which makes patients access to view hard to be achieved. Tinted glass is used for windows in both ICUs.

Beds' layout is arranged such that patients face the interior. Therefore, there is no access to view except for one patient in the isolation room in each ICU.

Daylight measurements targeted a patient area within the open plan ward of the surgical ICU and an isolation room and a patient area within the open plan ward in the medical ICU, as shown in Figure 6.21 and 6.22. The detailed measurement results are in Appendix A.

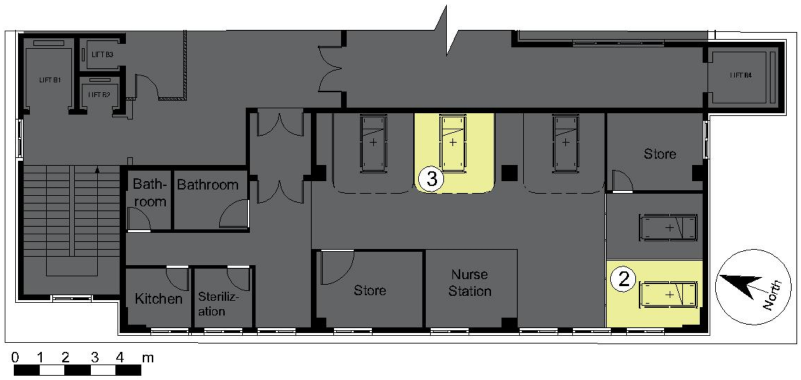
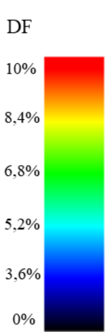
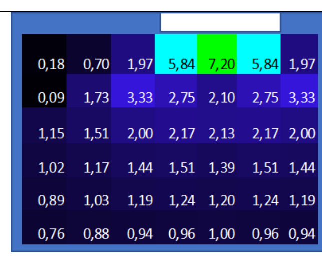
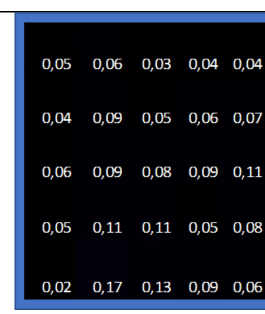


Figure 6.22: ICU patient areas in An-Najah National University Hospital where the average daylight factor was measured.
Source: The engineering department of An-Najah National University (edited by author).

Table 6.6: The field measurements of the selected patient areas of the ICU in An-Najah National University Hospital

Patient area number	1	2	3
Area type	Patient area within an ICU ward (Surgical ICU)	Isolation room (Medical ICU)	Patient area within an ICU ward (Medical ICU)
Orientation	South	West	---
Widow to wall ratio	46%	18%	0
Window lintel level height	218 cm	198 cm	218 cm
Window sill level height	83 cm	26 cm	83 cm
Average daylight factor	2,35%	1,83%	0,07%
Measured daylight factor map 			
Average illuminance	358 lux	254 lux	10 lux
Access to view	No access to view	Achieved	No access to view
Measurements were taken under overcast sky conditions during the morning from 8:00 AM to 8:30 AM in 9/9/2020.			

Daylight measurements, presented in Table 6.6, show that the required average daylight factor is not achieved in all studied rooms even room 1 despite its high window-to-wall ratio. This is probably due to the use of tinted glass.

6.2.6.2. The Incidence of Delirium

In the interview recorded with I.S., a nurse in the surgical ICU of An-Najah National University Hospital: ICU delirium is common for surgical ICU patients (Sarees, 2020). It is common as well for patients in the medical ICU according to W.A., a senior nurse in the medical ICU. Those patients are treated only by medication. Apart from enhancing the environment (Abu-Omar, 2020).

6.3. Optimization of the Parameters Affecting Daylight

6.3.1. Simulation Validity Check

Daylight simulation were conducted to the studied patients' areas of the ICUs of Alahli and Alia Governmental hospitals to compare the results to the field measurement results mentioned in this chapter, Section 6.2. Moreover. The average daylight factor for the studied rooms were calculated by the GBI daylight calculation tool (Green Building Index) using the BRE and Sumpner formulas, which state that:

BRE formula

$$DFm, BRE = (Awindow\ \alpha\ M\ t) / (Atotal (1 - \rho m^2))$$

Sumpner formula

$$DFm, Sumpner = (Awindow\ \alpha\ M\ t) / (2\ Atotal (1 - \rho m))$$

Where $Awindow$ is surface area of the window, excluding frame, bars and other obstructions, $Atotal$ is total internal surface area of the room, α is angle of visible sky from the mid-point of the window, *M* is maintenance factor of the window, t is transmission factor of the glazing and ρm is average reflection factor of all internal surfaces (Green Building Index, 2020)**.**

This process aimed to chick the validity of simulation results when compared with field measurements and calculations. Table 6.7 shows the results of the daylight measurement, calculation and simulation of the same patients' areas.

Table 6.7: Measurement, calculation and simulation results of the average daylight factor in the ICU patient's areas of Alahli Hospital and Alia Governmental Hospital

Patient's area number		Measurement result	Simulation result	Calculation results	
				BRE formula	Sumpner formula
Ahli Hospital	1	1.550	1.039	1.1	0.8
	2	0,150	0,113	0.3	0.2
	3	0,02	0,07	0.1	0.1
Alia Governmen	1	2,36	2,87	2.4	2.0
	2	0.0	0.0	0.0	0.0

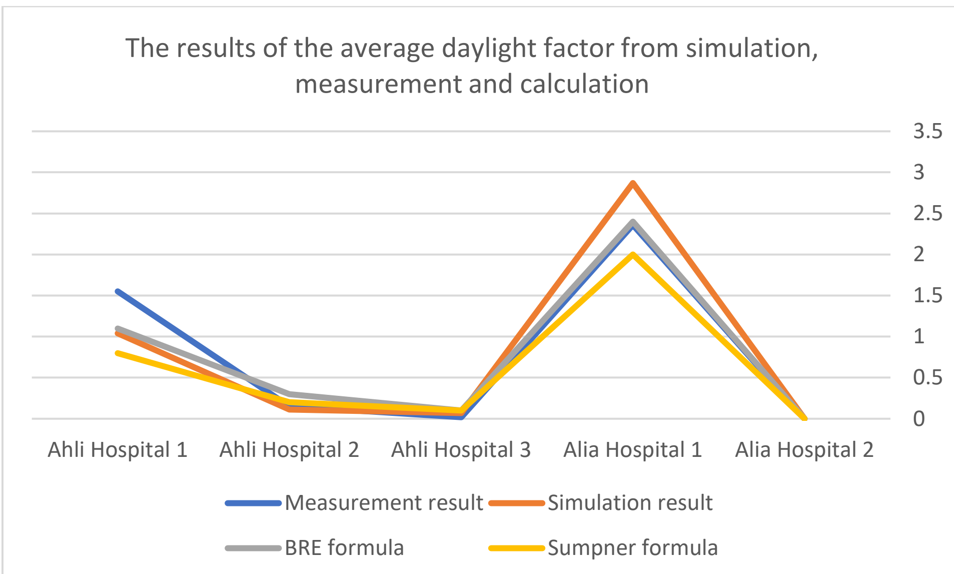


Figure 6.23: The results of the average daylight factor from simulation, measurement and calculations

Figure 6.23 shows that the simulation results as well as the field measurements and calculation results are relatively closed, with higher deviation in the higher values of average daylight factor. The differences between the simulated, calculated and measured values are probably due to the presence of dust on windows, the difference between the number of recorded points in the patient areas in field measurement and software simulation as well as personal and technical errors.

6.3.2. Single/Isolated ICU Room

6.3.2.1. Orientation

Eight simulation trials of the ICU single/isolated room were tested with an orientation change of 45° each time, as presented in Figure 6.24. Other parameters were kept constant; window to wall ratio was 30%, window height was 1.5m, window lentil level height was 2,3m, light reflectance value of the interior surfaces was 0,5 and no shading device was used.

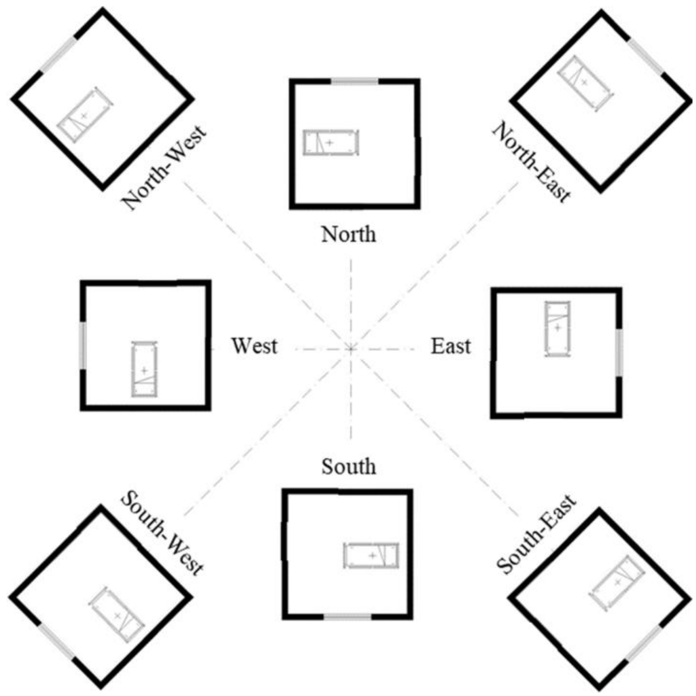


Figure 6.24: Simulation cases of the ICU single/isolated room with orientation change.

Table 6.8 below shows the simulation results of the average daylight factor and the annual energy consumption in KWH and MJ in the previously mentioned orientation cases.

Table 6.8: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room according to the orientation change

Orientation	North	North-East	East	South - East	South	South-West	West	North-West
Average daylight factor (%)	3,406	3,746	3,44	3,721	4,125	3,623	4,156	3,68
Heating and cooling loads (KWH)	13493	13637	13649	13497	13274	13619	13842	13789
Heating and cooling loads (10^4 MJ)	4,857	4,909	4,914	4,859	4,779	4,903	4,983	4,964

Simulation results show that the west and south are the best orientations in terms of the provision of the highest daylight factor. However, west orientation is associated with the highest annual energy consumption, which might probably be due to the low altitude sun angle in this direction (Hanieh, 2019), which in turn results in increasing heat gain. Moreover, the west and east orientations of windows may cause glare unless effective shading devices are used (Aripin, 2007). On the other hand, the minimum energy consumption values were recorded in south and north orientations. Therefore, South orientation is considered the optimal orientation in terms of daylighting and energy consumption in Palestine climate, which scored an average daylight factor of 4,125%. This result is evident in the diagram in Figure 6.25. Furthermore, in the case of the ICU multi-bed ward, the south-north orientation is probably the best orientation of the longer and glazed sides of the ward, which would provide acceptable daylighting without increasing heat gains or causing glare. However, results were unexpected, as it is expected that the values of the average daylight factor will not be affected by orientation, since there is no effect of direct sunlight on the indoor illuminance in an overcast sky.

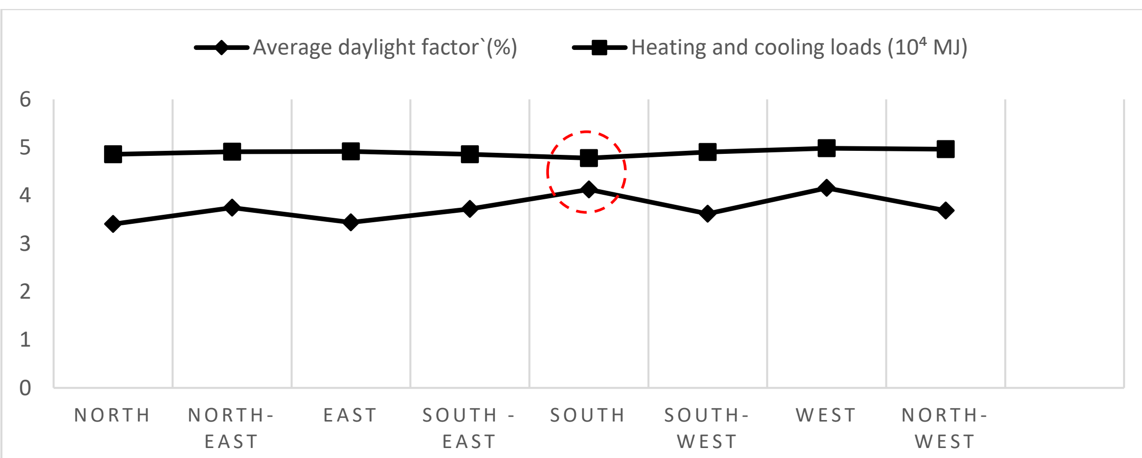


Figure 6.25: Average daylight factor and annual energy consumption in different orientations of the ICU single/isolated room

6.3.2.2. Window Lintel Level Height

The window lintel level height was optimized by conducting simulation trials of different heights, with a height change of 25cm for each trial (the typical height of cladding stone used in

Palestine) as shown in Figure 6.26. Other parameters were kept constant; window to wall ratio was 30%, window height was 1.5m, light reflectance value of the interior surfaces was 0.5 and no shading device was used.

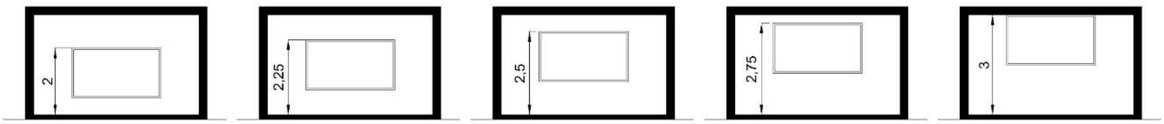


Figure 6.26: Simulation cases of the ICU single/isolated room with the change of lintel level height

Table 6.9: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room according to the lintel level height change

Window sill level hight (m)	2	2.25	2.5	2.75	3
Average daylight factor (%)	3,526	4,212	4,094	3,719	3,441
Heating and cooling loads (KWH)	13274	13274	13274	13273	13272
Heating and cooling loads (10^4 MJ)	4,7786	4,7786	4,7786	4,7783	4,7779

Simulation results show that there is a significant impact of the window level on the daylight factor of the space, unlike the energy consumption, where no noticeable variation resulted from the change of window lintel level recorded, as shown in Figure 6.27.

The height of 2,25 scored the highest average daylight factor, making it the optimal height of the window lintel level in terms of daylighting as shown in Table 6.9. Implementing the optimal orientation and window sill height together raised the daylight factor from 4,125% to 4,212%.

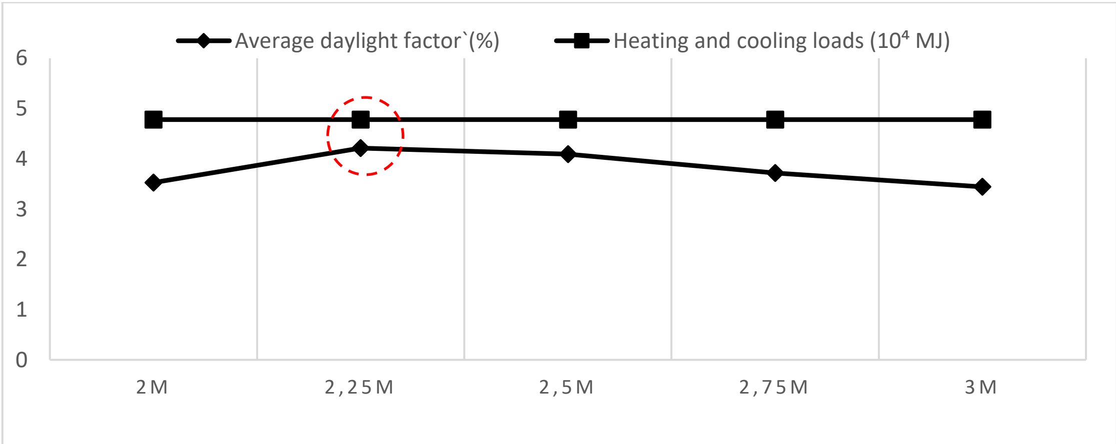


Figure 6.27: Average daylight factor and annual energy consumption in different lentil level height in the studied room

6.3.2.3. Window to Wall Ratio

Window to wall ratio was tested for the studied room such that five simulation trials were conducted with a change of 10% of window to wall ratio for each one, taking (10%, 20%, 30%, 40% and 50%) as simulation cases, as shown in Figure 6.28 below. Window height was constant, while window width varied as per the required ratio. Other parameters were constant; window lintel level height was 2,25m, window height was 1,5m, light reflectance value of the interior surfaces was 0.5 and no shading device was used.

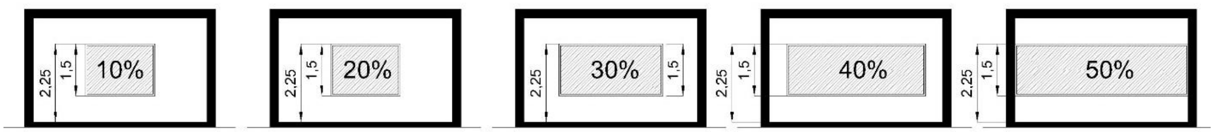


Figure 6.28 Simulation cases of the studied room with the change of window to wall ratio

Simulation results, which are shown in Table 6.10, show that the more the window to wall ratio, the higher the daylight factor and the higher energy consumption. Ratio values below 30% lead to unacceptable daylight factor (less than 3%), while values more than 30% resulted in more energy consumption.

Table 6.10: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room according to the change of window to wall ratio

Window to wall ratio	10%	20%	30%	40%	50%
Average daylight factor (%)	1,155	2,728	4,212	5,611	6,826
Heating and cooling loads (KWH)	13194	13203	13274	13401	13575
Heating and cooling loads (10^4 MJ)	4,74984	4,75308	4,77864	4,82436	4,887

Window to wall ratio of 30% achieved the optimization equation, that provides the minimum heating and cooling load when the daylight factor is more than the minimum acceptable value of 3%. The diagrams in Figure 6.29 clarify the significant relationships between window to wall ratio and the simulation results of daylight factor as well as the annual energy consumption for heating and cooling. Daylight factor was found to have a linear relationship with window to wall ratio.

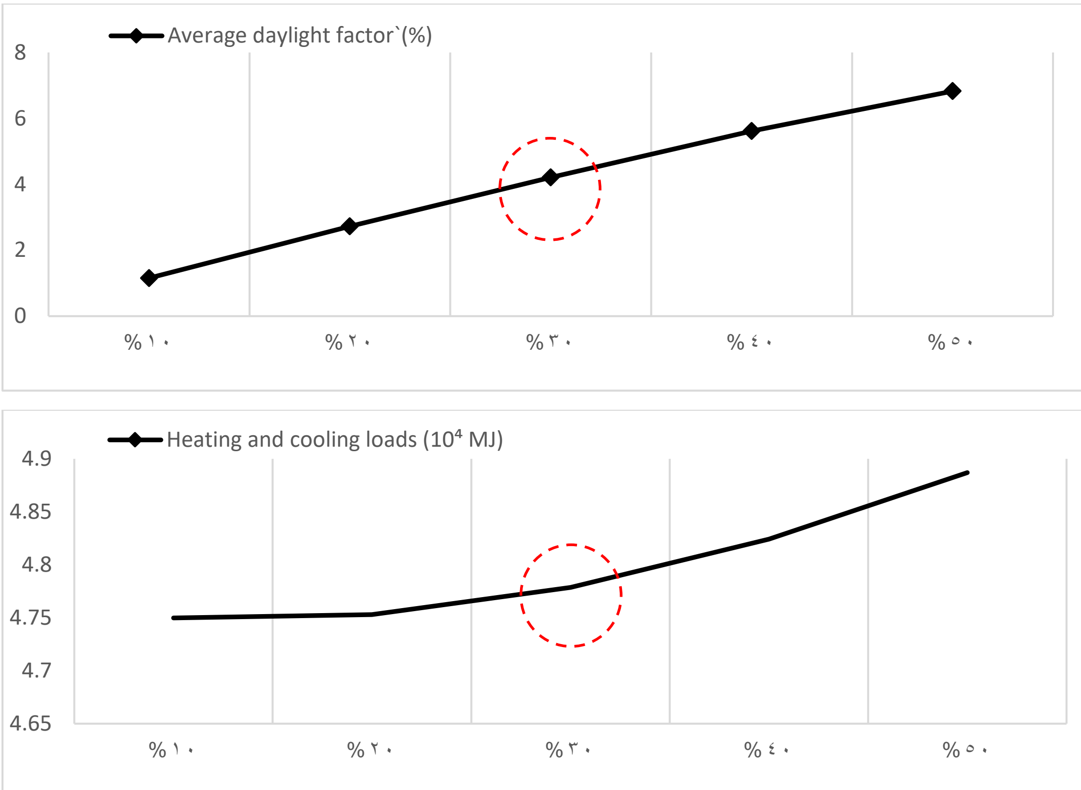


Figure 6.29: Average daylight factor and annual energy consumption in different window to wall ratios in the ICU single/isolated room

6.3.2.4. Walls' Interior Surfaces Material and Colour

The relationships between the average light reflectance value of the inner surfaces of the walls and the daylight factor, heating and cooling loads and the uniformity ratio were investigated by conducting simulation trials with a variation of 0,1 of light reflectance value, without changing the thermal properties. The input range of the light reflectance value was from 0,1 as a minimum value to 0,9 as a maximum value. Simulation results show a significant relationship between light reflectance value and the average daylight factor of the room as well as the uniformity ratio; the higher light reflectance value, the higher average daylight factor and the better light distribution.

However, heating and cooling loads remained constant while the variation of light reflectance value as shown in Table 6.11.

Table 6.11: Simulation results of the average daylight factor, the annual heating and cooling loads and the uniformity ratio of the ICU single/isolated room according to the change of light reflectance value.

The average light reflectance value	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
Average daylight factor	3,679	3,785	3,922	4,052	4,212	4,341	4,552	4,792	5,0
Heating and cooling loads (KWH)	13274	13274	13274	13274	13274	13274	13274	13274	13274
Heating and cooling loads (10^4 MJ)	4,77864	4,77864	4,77864	4,77864	4,77864	4,77864	4,77864	4,77864	4,77864
Uniformity Ratio	0,058	0,076	0,106	0,124	0,154	0,182	0,223	0,285	0,321

The diagram in Figure 6.30 shows that the relationship between daylight factor and light reflectance value is linear. A high reflectance value can be achieved through the use of smooth and light color paints of walls, for example, the light reflectance value of the white paint ranges from 0.75 to 0.85. However, the most common paint color of the walls of hospital rooms is light green, which has a reflectance value of 0.45 to 0.55 (Engineering ToolBox, 2012).

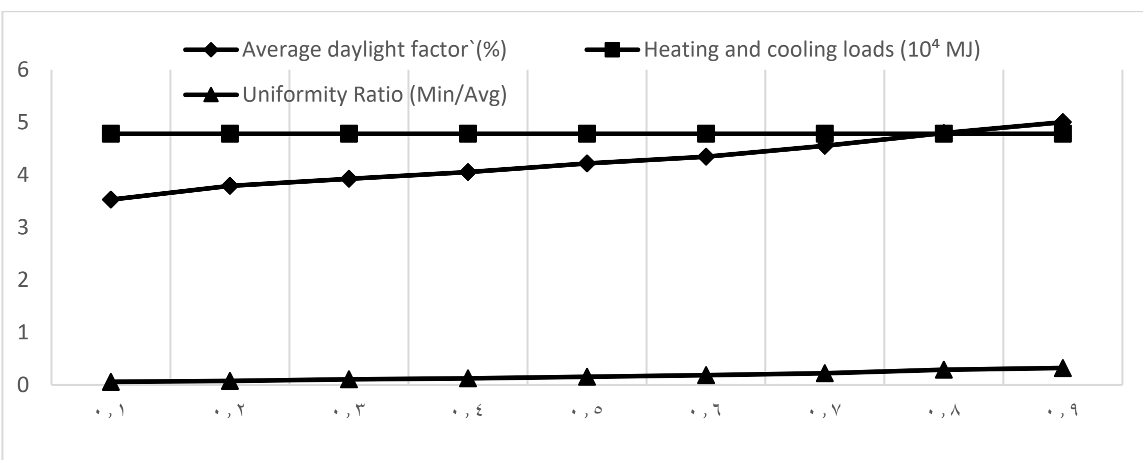


Figure 6.30: Average daylight factor and annual energy consumption in different lentil level height in the ICU single/isolated room

6.3.2.5. Shading Device

A horizontal shading device is the appropriate solution for south-oriented facades in the Mediterranean climate (Jorge, et al., 1993); (Kirimtat, et al., 2016). The shading device optimization process had two phases: the first aimed to determine the optimal position of the shading device (its level height from window sill) and the second aimed to optimize its depth.

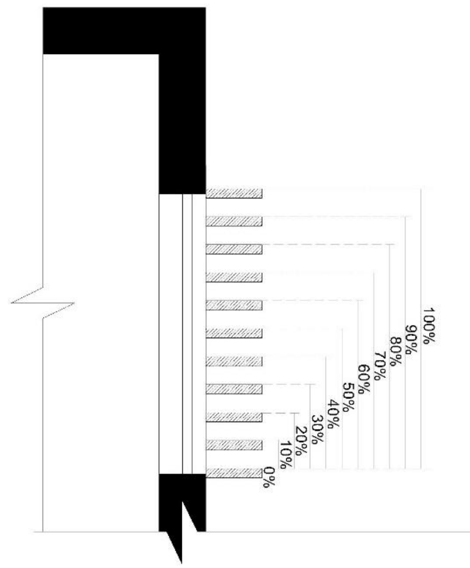


Figure 6.31 : Simulation cases of the studied room with the change of horizontal shading device level height

The first phase of the simulation was based on gradually increasing the level height of the shading device by 10% of the window height, starting from 0% (at the window sill level) up to 100% (at the window lintel level). Simulation cases are shown in Figure 6.31. The simulation process was conducted while the shading device's depth was 20% of the window height, light reflectance values of the walls' inner surfaces and the shading device were 0,9 and 0,8 respectively, window height was 1,5m, window lintel level height was 2,25m, window wall ratio was 30%.

Simulation results show that shading device presence reduces the average daylight factor in the room on one hand, and reduces the amount of annual energy consumed for heating and cooling on the other. The maximum amount of energy can be saved when the shading device position is directly above the window, while the average daylight factor remains within the required value. The simulation was repeated for this case (shading device above the window) after changing the walls surface reflectance value from 0,9 to 0,5 to ensure that daylight factor will be as required, since 0,9 may be ideal since real rooms include furniture and equipment that might affect light reflectance and to comply with the reflectance value of light green, which is commonly used in hospital rooms. The resulted daylight factor of this simulation trial was 3,485%, which is within the standard values. A horizontal plane of a reflecting surface can be used at the window sill level (0% of window height) to enhance daylighting without negatively affect the energy consumption. shading devices can also reduce the incidence of glare (Manzan & Pinto, 2009).

Simulation results of the average daylight factor and the annual heating and cooling loads of the studied room according to the change of shading device level height are presented in Table 6.12 below.

Table 6.12: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room according to the change of shading device level height from window sill height.

Shading device level height (as a percentage of window height)	100% (at the lentil level)	90%	80%	70%	60%	50%	40%	30%	20%	10%	0% (at the sill level)	Without shading device
Average daylight factor	4,194	3,826	3,905	4,027	4,051	4,151	4,202	4,44	4,714	4,888	5,030	5,0
Heating and cooling loads (KWH)	13196	13196	13198	13202	13206	13213	13222	13233	13249	13261	13271	13274

The second phase of shading device optimization was conducted based on changing the depth of the shading device by an amount that is equivalent to a percentage of 10% of the window height, starting with 10% up to 100% as shown in Figure 6.32. While other parameters were constant; window to wall ratio was 30%, window height was 1,5m, window lintel level was 2,25m, light reflectance values of the wall's inner surfaces and the shading device were 0,9 and 0,8 respectively and the used shading device was an overhang.

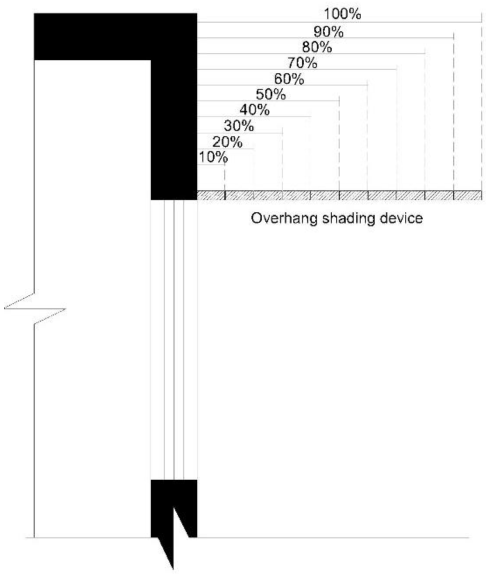


Figure 6.32: Simulation cases of the studied room with the change of horizontal shading device depth

Simulation results show that heating and cooling loads gradually decrease while increasing the depth of the shading device from 10% up to 40% passing by 20% and 30% of the window height and they go back to increase when increasing the depth of more than 40% of the window height. Whereas, the average daylight factor decreases when increasing the window depth.

Although the depth of 40% of the window height achieved the highest energy saving, the latter is not significantly different from the energy-saving related to a depth of 30% of window height (only 3KWH difference, which is negligible according to the study assumption), while more daylight factor was achieved by a depth of 30% than 40% of the window height. Therefore, a percentage of 30% of the window height is considered the optimal depth of the overhang shading device. The simulation of the case of 30% depth was repeated by changing the light reflectance value of the inner surfaces of walls from 0,9 to 0,5, to ensure that the average daylight factor remains more than 3%. The average daylight factor resulted was 3,188% which is an acceptable value. The result of the shading device depth complies with the formula formulated by "2030 Palette project" of the overhang projection which states that

$$P = H/F$$

Where P is the shading device projection, H is window height and F is a factor based on the latitude. For Palestine, the factor ranges from 3 to 6,3 (2030 palette,2020). That means that according to this resource, overhang depth should be 15% to 33% of the window height.

Shading devices may be more effective when using transparent material such as clear plastic with a reflective coating (Olbina & Beliveau, 2009). Simulation results of the overhang shading device depth are shown in Table 6.13.

Table 6.13: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room according to the change of overhang shading device depth of the south oriented window.

shading device depth (as a percentage of window height)	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average daylight factor	4,630	4,194	3,825	3,490	3,233	3,018	2,876	2,706	2,549	2,464
Heating and cooling loads (KWH)	13230	13196	13180	13177	13182	13193	13208	13226	13243	13262

The steps of the optimization process are presented in Figure 6.33, where the optimization results of each parameter are shown. It can be noticed that the result of each step was used as a simulation input for the step next to it, and so on; to consider the impact of each parameter on the others.

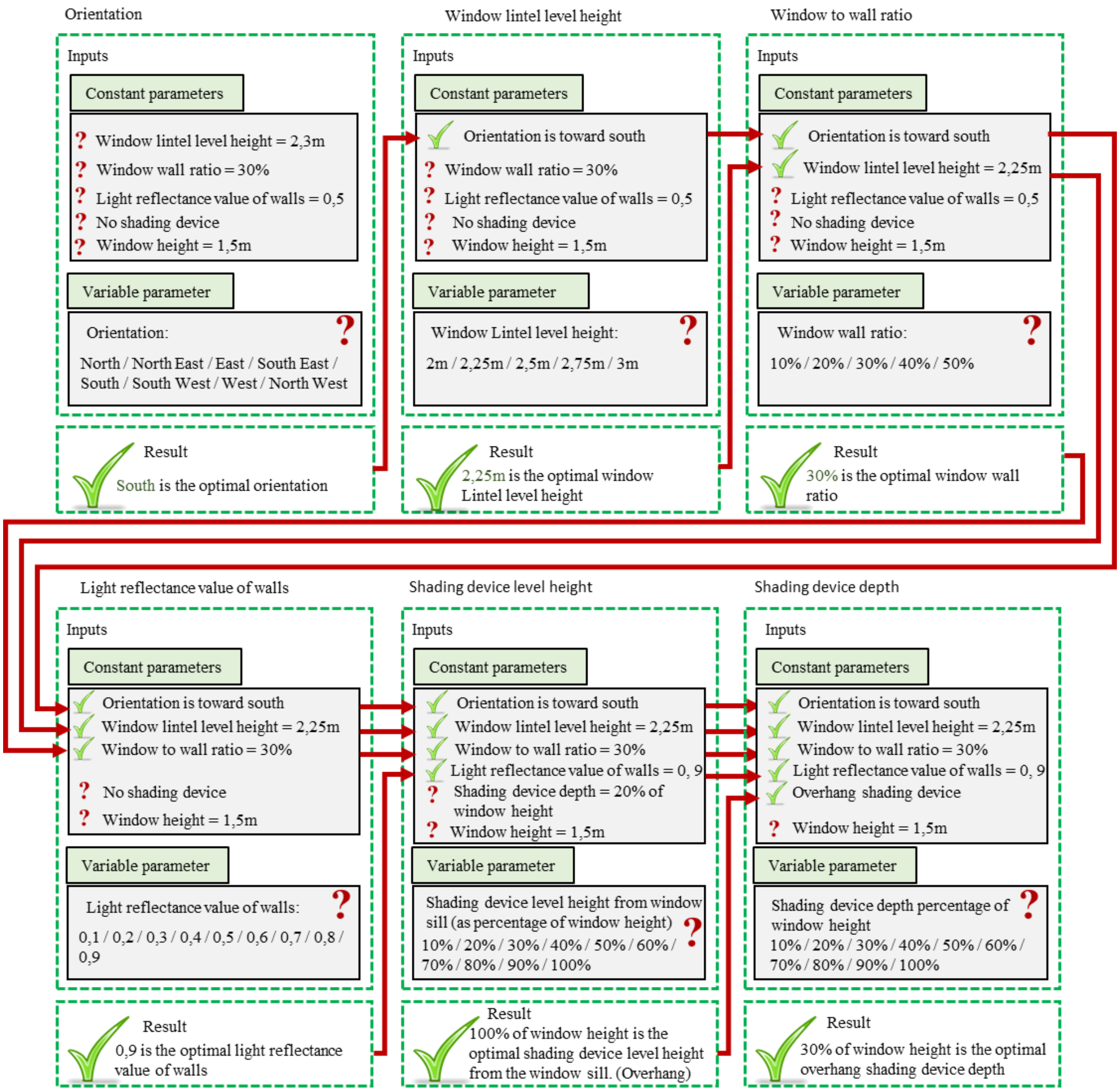


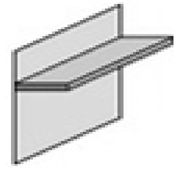
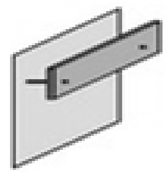
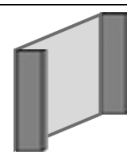
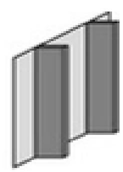
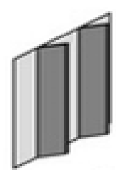
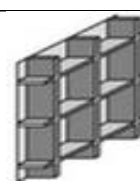
Figure 6.33: The steps of the optimization process of the single/isolated room

6.3.3. Orientation Scenarios

North, north-east, east, south-east, south-west, west and north-west orientation scenarios were tested to investigate the optimized window lintel level height, window to wall ratio and shading device that are related to each orientation.

Vertical shading device was proposed to the north-east, east, west and north-west elevations, such that simulation trials were done to investigate the influence of the vertical shading device's depth on the average daylight factor as well as the energy consumption for heating and cooling, starting with a depth of 10% to 60% of the window width with an increment of 10% for each trial, where overhang shading device was not proposed for these orientations since it has no significant influence on non-southern facades due to the sun low

Table 6.14: General types of shading devices

	Shading device type	3D view	View restriction
Horizontal shading devices	Horizontal panel		Not restricted
	Horizontal louvers in vertical plane		Restricted
	Vertical Plane		Restricted
Vertical shading devices	Side-fins		Not restricted
	Slanted vertical fins		Restricted
	Vertical fins		Restricted
Eggcrate	Eggcrate		Restricted
	Eggcrate with horizontal louvers		Restricted

* Source: (El Sherif, 2012); (AIA & SBSE, 2012); (Lechner, 2014)

angles in these directions (AIA & SBSE, 2012); (Kirimtat, et al., 2016). Combined shading device (both overhang and vertical) was proposed for south-east and south-west oriented windows, while no shading devices were proposed to north elevation since sun penetration does not occur at north windows (in the northern hemisphere) except in the early morning and late evening in very low angles in summer and no significant heat gains result. Therefore, no shading device is required (AIA & SBSE, 2012). The selection criteria of shading devices types based on achieving high performance without restricting the outside view, which was based on the classification of shading devices in Table 6.14. Side-fins and horizontal panel were selected as vertical and horizontal shading devices respectively. Table 6.15 shows the types of shading devices that are proposed in different orientation scenarios.

Table 6.15: The proposed shading device types for different orientation scenarios

	North	North-east	East	South-east	South-west	West	North-west
Overhang shading device				✓	✓		
Vertical shading device		✓	✓	✓	✓	✓	✓

6.3.3.1. North

Simulation results of window lintel level height and window to wall ratio are presented in Table 6.16 and 6.17 respectively. The highest amount of the average daylight factor was recorded at a window lintel level height of 2,5m, while the heating and cooling loads remained constant. Window to wall ratio below 30% did not achieve the requirement of the average daylight factor, while the more window to wall ratio, the more heating and cooling loads. A ratio of 30% is, therefore, considered the optimized value; that achieves daylight requirement with minimal energy consumption as possible.

Table 6.16: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at north orientation according to the lintel level height change*

Window lintel level hight (m)	2	2.25	2.5	2.75	3
Average daylight factor (%)	2,697	3,313	3,604	3,566	3,240
Heating and cooling loads (KWH)	13492	13492	13492	13492	13492

* Window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 30%, 0.5 and 1,5 m respectively and no shading device was used.

Table 6.17: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at north orientation according to the change of window to wall ratio *

Window to wall ratio	10%	20%	30%	40%	50%
Average daylight factor (%)	1,010	2,335	3,604	4,765	5,684
Heating and cooling loads (KWH)	13355	13422	13492	13566	13639

* Window lintel level height, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 0.5 and 1,5m respectively and no shading device was used.

6.3.3.2. North-East

As the north orientation, simulation results presented in Table 6.18 and 6.19 show that the optimal values of daylight factor as well as the energy consumption for heating and cooling can be achieved at a window lintel level height of 2,5m and a window to wall ratio of 30%.

Table 6.18: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at north-east orientation according to the change of window lintel level height *

Window sill level height (m)	2	2.25	2.5	2.75	3
Average daylight factor	3,017	3,747	3,885	3,473	3,396
Heating and cooling loads (KWH)	13636	13636	13636	13636	13635

* Window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 30%, 0.5 and 1,5 m respectively and no shading device was used.

Table 6.19: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at north -east orientation according to the change of window to wall ratio *

Window to wall ratio	10%	20%	30%	40%	50%
Average daylight factor (%)	1,081	2,503	3,885	5,024	6,019
Heating and cooling loads (KWH)	13409	13520	13636	13754	13870

* Window lintel level height, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 0.5 and 1,5m respectively and no shading device was used.

Table 6.20: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at north-east orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3,779	3,71	3,612	3,553	3,505	3,481
Heating and cooling loads (KWH)	13621	13608	13599	13591	13586	13582

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and no horizontal shading device was used.

Simulation results show that the higher depth of the shading device, the lower energy consumption for heating and cooling. However, the impact of the proposed shading device was found to be insignificant when the depth is more than 20% of window width since the reduction in energy consumption for heating and cooling did not exceed 9 KWH when changing the depth by 10% of window width. Moreover, a high projection may affect the elevation form negatively without significantly minimize heating and cooling loads. Therefore, 20% of window width is considered the optimized depth of the vertical shading device in north-east oriented windows. The simulation results of the vertical shading device depth are shown in Table 6.20.

6.3.3.3. East

Based on simulation results shown in Table 6.21, the highest average daylight factor was achieved when window lintel level height equals 2.5m, while heating and cooling loads remained constant. As for the window to wall ratio, which shown in Table 6.22, a value of 30% achieved minimal energy consumption and a daylight factor within the requirements.

Table 6.21: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at east orientation according to the change of window lintel level height *

Window lintel level height (m)	2	2.25	2.5	2.75	3
Average daylight factor	2,708	3,313	3,629	3,528	3,284
Heating and cooling loads (KWH)	13649	13648	13648	13648	13647

* Window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 30%, 0.5 and 1,5 m respectively and no shading device was used.

Table 6.22: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at east orientation according to the change of window to wall ratio *

Window to wall ratio	10%	20%	30%	40%	50%
Average daylight factor (%)	1,034	2,333	3,629	4,823	5,697
Heating and cooling loads (KWH)	13380	13505	13648	13806	13971

* Window lintel level height, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 0.5 and 1,5m respectively and no shading device was used.

On the other hand, the impact of the vertical shading device on the east oriented windows was insignificant, as shown in Table 6.23. This probably is due to the loss of sun penetration potentials in winter, which in turn would increase the heating loads on cold days. Moreover, the use of side-fins shading devices may not be significant in east orientation compared to multiple vertical fins or eggcrate (AIA & SBSE, 2012). Vegetative Shading can be used as an alternative solution for window shading if the ICU is located on low-level floors (AIA & SBSE, 2012). Treated glass can be used in these orientations as well; reflective glass, glass treated with nanotechnology, tinted glass and ultraviolet filtering technology are examples for it (Tuchinda, et al., 2006); (Abdin, et al., 2018); (Gorantla, et al., 2018).

Table 6.23: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at east orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3,574	3,459	3,375	3,350	3,296	3,309
Heating and cooling loads (KWH)	13652	13657	13656	13657	13659	13659

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and no horizontal shading device was used.

6.3.3.4. South- East

The same as the previous scenarios, the highest daylight factor, as well as the minimal heating and cooling loads, were recorded at a window lintel level height of 2.5m and a window to wall ratio of 30%. This can be seen in Table 6.24 and 6.26.

Table 6.24: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south-east orientation according to the change of window lintel level height *

Window lintel level hight (m)	2	2.25	2.5	2.75	3
Average daylight factor (%)	2,942	3,599	3,898	3,642	3,419
Heating and cooling loads (KWH)	13497	13497	13497	13497	13495

* Window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 30%, 0.5 and 1,5 m respectively and no shading device was used.

Table 6.25: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south-east orientation according to the change of window to wall ratio *

Window to wall ratio	10%	20%	30%	40%	50%
Average daylight factor (%)	1,060	2,506	3,898	5,103	6,011
Heating and cooling loads (KWH)	13321	13385	13497	13641	13808

* Window lintel level height, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 0.5 and 1,5m respectively and no shading device was used.

As for the shading device, it was optimized twice differently. First, the vertical device was only used and its depth was changed 6 times with an increment of 10% of window width, and the optimum depth was obtained and used as a simulation input for optimizing the horizontal device, which was tested 5 times with different depths ranging from 10% to 50% of the window height, to determine the optimum values of both shading devices together. While at the second method, the horizontal shading device's depth was tested first, then the result of the optimum depth was used as an input in the optimization process of the vertical one's depth.

Simulation results of the first method (Vertical shading device was tested before the horizontal) that are presented in Table 6.26 and 6.27, show that the vertical shading device depth that achieved a reduction of more than 10 KWH from heating and cooling loads and acceptable value of daylight factor was equivalent to 30% of window width. While the associated optimized depth of the horizontal shading device is equivalent to 10% of the window height. This combination reduced the energy consumption for cooling and heating from 13497KWH to 13426KWH.

Table 6.26: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south- east orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3,801	3,679	3,626	3,573	3,519	3,473
Heating and cooling loads (KWH)	13482	13478	13461	13454	13450	13446

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and no horizontal shading device was used.

Table 6.27: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south- east orientation according to the change of the horizontal shading device depth *

shading device depth (as a percentage of window height)	10%	20%	30%	40%	50%
Average daylight factor (%)	3,309	2.969	2,65	2,356	2,143
Heating and cooling loads (KWH)	13426	13394	13369	13353	13345

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and the depth of the vertical shading device was 30% of window width.

On the other hand, the results of the second method (the horizontal shading device was tested before the vertical), which found that the optimized values of the horizontal and vertical shading devices were 20% of window height and 20% of window width respectively, were more significant, as the reduction of heating and cooling loads was from 13497KWH to 13402KWH. The second method results are shown in Table 6.28 and 6.29.

Table 6.28: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south- east orientation according to the change of the horizontal shading device depth *

shading device depth (as a percentage of window height)	10%	20%	30%	40%	50%
Average daylight factor (%)	3,598	3,272	2,964	2,746	2,542
Heating and cooling loads (KWH)	13459	13422	13393	13373	13361

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and no vertical shading device was used.

Table 6.29: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south- east orientation according to the change of the horizontal shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%
Average daylight factor (%)	3.171	3,032	2,971	2,903	2,919
Heating and cooling loads (KWH)	13412	13402	13394	13389	13385

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and the depth of the horizontal shading device was 20% of window height.

6.3.3.5. South- West

Simulation results of south-west orientation show that the optimal daylighting, as well as the minimal heating and cooling loads, can be achieved at a window lintel level height of 2,5m and a window to wall ratio of 30%, as shown in Table 6.30 and 6.31.

Table 6.30: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south-west orientation according to the change of window lintel level height *

Window lintel level hight (m)	2	2.25	2.5	2.75	3
Average daylight factor (%)	2,839	3,478	3,906	3,666	3,354
Heating and cooling loads (KWH)	13618	13618	13618	13617	13615

* Window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 30%, 0.5 and 1,5 m respectively and no shading device was used.

Table 6.31: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south-west orientation according to the change of window to wall ratio *

Window to wall ratio	10%	20%	30%	40%	50%
Average daylight factor (%)	1,082	2,533	3,906	5,133	6,037
Heating and cooling loads (KWH)	13340	13446	13618	13841	14104

* Window lintel level height, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 0.5 and 1,5m respectively and no shading device was used.

Shading devices were tested using the two methods applied in the south-east orientation. The results of the first proposed a depth of the vertical shading device that is equivalent to 50% of window width, and a depth of the horizontal of 10% of the window height, this can reduce the heating and cooling loads from 13618KWH to 13453KWH.

Table 6.32: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south- west orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3,787	3,683	3,584	3,514	3,523	3,510
Heating and cooling loads (KWH)	13584	13553	13530	13511	13497	13489

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and no horizontal shading device was used.

Table 6.33: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south- west orientation according to the change of the horizontal shading device depth *

shading device depth (as a percentage of window height)	10%	20%	30%	40%	50%
Average daylight factor (%)	3,245	2,863	2,552	2,258	2,025
Heating and cooling loads (KWH)	13453	13409	13373	13347	13330

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and the depth of the vertical shading device was 50% of window width.

While the second method proposed a depth of 20% of window height for the horizontal shading device and 20% of window width for the vertical, this reduces the heating and cooling loads from 13618KWH to 13459KWH, which is not far from the first result. Although the two options are almost the same in terms of energy consumption, the first method provides more daylight factor than the second by 0.234%. Therefore, 50% and 10% are the optimized values of the vertical and horizontal shading devices respectively. The results of the first method are shown in Table 6.32 and 6.33, while Table 6.34 and 6.35 show the results of the second.

Table 6.34: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south- west orientation according to the change of the horizontal shading device depth *

shading device depth (as a percentage of window height)	10%	20%	30%	40%	50%
Average daylight factor (%)	3,547	3,253	2,905	2,667	2,501
Heating and cooling loads (KWH)	13567	13514	13469	13435	13411

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and no vertical shading device was used.

Table 6.35: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at south- west orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%
Average daylight factor (%)	3,141	3.011	2.919	2,894	2,871
Heating and cooling loads (KWH)	13487	13459	13436	13420	13409

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and the depth of the horizontal shading device was 20% of window height.

6.3.3.6. West

Simulation results of west orientation show that 2,5m and 30% are the optimized values of window lintel level height and window to wall ratio respectively. This can be noticed from Table 6.36 and 6.37. The same as east orientation, the impact of the vertical shading device was found insignificant, as the reduction of the heating and cooling loads did not exceed 4 KWH when increasing its depth by 10% of window width. The simulation results of the depth of the vertical shading device are shown in Table 6.38.

Table 6.36: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at west orientation according to the change of window lintel level height *

Window lintel level hight (m)	2	2.25	2.5	2.75	3
Average daylight factor (%)	3,322	3,996	3,886	3,534	3,259
Heating and cooling loads (KWH)	13841	13841	13840	13840	13837

* Window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 30%, 0.5 and 1,5 m respectively and no shading device was used.

Table 6.37: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at west orientation according to the change of window to wall ratio *

Window to wall ratio	10%	20%	30%	40%	50%
Average daylight factor (%)	1,054	2,539	3,886	5,270	6,209
Heating and cooling loads (KWH)	13423	13614	13840	14092	14355

* Window lintel level height, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 0.5 and 1,5m respectively and no shading device was used.

Table 6.38: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at west orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor	3,780	3,666	3,631	3,537	3,528	3,514
Heating and cooling loads (KWH)	13838	13836	13832	13830	13829	13828

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and no horizontal shading device was used.

6.3.3.7. North- West

As for north-west orientation, simulation results, shown in Table 6.39, 6.40 and 6.41, show that 2,5m is the best window lintel level height and 30% is the best window to wall ratio in term of the provision of the required daylight and the minimum energy consumption. While the impact of the vertical shading device was found significant, as the higher its depth, the lower heating and cooling load, a depth of 60% of window width can be used for the vertical shading device, however, if this projection negatively affects the architectural form, it can be reduced, as it can still be effective.

Table 6.39: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at north-west orientation according to the change of window lintel level height *

Window sill level hight (m)	2	2.25	2.5	2.75	3
Average daylight factor (%)	2,924	3,535	3,817	3,701	3,385
Heating and cooling loads (KWH)	13788	13788	13788	13788	13786

* Window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 30%, 0.5 and 1,5 m respectively and no shading device was used.

Table 6.40: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at north- west orientation according to the change of window to wall ratio *

Window to wall ratio	10%	20%	30%	40%	50%
Average daylight factor (%)	1,011	2,517	3,817	5,034	5,976
Heating and cooling loads (KWH)	13454	13616	13788	13967	14144

* Window lintel level height, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 0.5 and 1,5m respectively and no shading device was used.

Table 6.41: Simulation results of the average daylight factor and the annual heating and cooling loads of the ICU single/isolated room at west orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3,777	3,67	3,56	3,517	3,484	3.475
Heating and cooling loads (KWH)	13770	13761	13734	13720	13709	13698

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and no horizontal shading device was used.

The concluded optimum values of window lintel level height, window to wall ratio and shading device depth that related to each orientation for the ICU single/isolated room are shown in Figure 6.34.

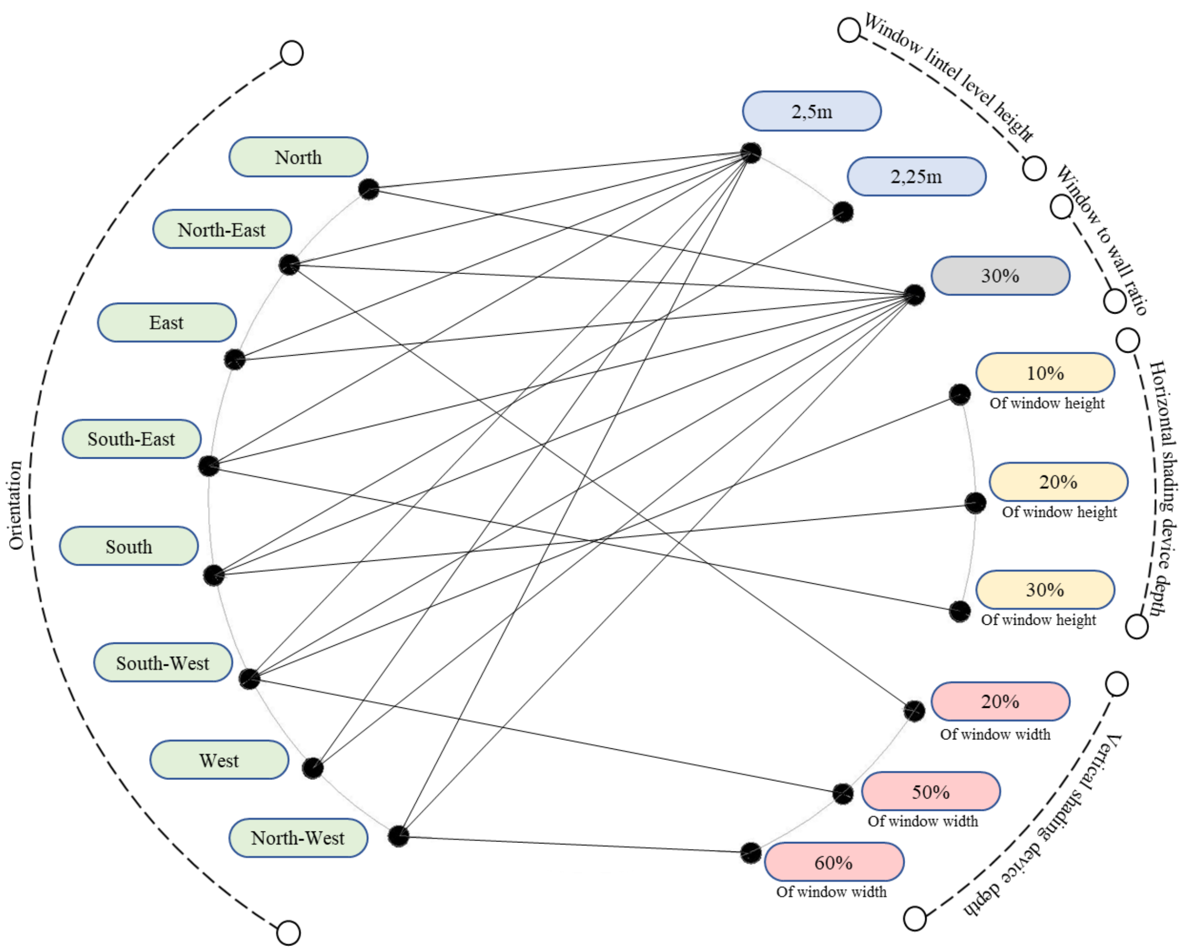


Figure 6.34: The optimum values of window lintel level height, window to wall ratio and shading device depth that related to each orientation for the ICU single/isolated room

6.3.4. The Two-Bed ICU Room

The same optimization process was conducted to the two-bed ward model in order to determine the parameters that achieve the optimal daylight and the minimal heating and cooling loads. Due to the similarity of the solar path, the optimized orientation would be the same for all models and the result of the single room model can be generalized to the others. The results of light reflectance value will be the same as well; as its value related to material properties (smoothness and color) (MaterialsCouncil, 2012), and according to the previous results: the higher light reflectance value, the higher daylight factor and the better light distribution regardless of the shape of space. Therefore, the parameters that were optimized for the two-bed room model are window lintel level height, window to wall ratio and the shading devices depth.

6.3.4.1. Window Lintel Level Height

Window lintel level height was tested for the two-bed ICU room, for all orientations, while other parameters were constant; window to wall ratio was 30%, window height was 1,5m, light reflectance value of the inner surfaces of the walls was 0,5 and no shading devices were used.

Simulation results of the average daylight factor and the heating and cooling loads according to the change of window lintel level for all orientations are shown in Table 6.42 below. The highest values of average daylight factor were recorded at a window lintel level of 2.5m for north, north-east, east, south-west and west oriented windows, 2.25m for south-oriented windows and 2.75m for south-east oriented windows as shown in the diagram in Figure 6.35.

Table 6.42: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed-ICU room at all orientations according to the change of window lintel level height *

Window orientation	Window lintel level hight (m)	2	2.25	2.5	2.75	3
North	Average daylight factor (%)	1,558	1,928	2,129	2,118	1,978
	Heating and cooling loads (KWH)	27420	27421	27421	27421	27420
North-East	Average daylight factor (%)	1,646	2,010	2.228	2,212	2,114
	Heating and cooling loads (KWH)	27568	27568	27568	27568	27567
East	Average daylight factor (%)	1,566	1,918	2,131	2,125	2,014
	Heating and cooling loads (KWH)	27534	27534	27534	27534	27532
South-East	Average daylight factor (%)	1,847	1,956	2,215	2,225	2,090
	Heating and cooling loads (KWH)	27347	27347	27347	27347	27346
South	Average daylight factor (%)	1,939	2,308	2,267	2,134	2,019
	Heating and cooling loads (KWH)	27062	27062	27062	27062	27062
South-West	Average daylight factor (%)	1,829	2,211	2,361	2,224	2,107
	Heating and cooling loads (KWH)	27466	27466	27466	27466	27464
West	Average daylight factor (%)	1,939	2,308	2,311	2,150	2,032
	Heating and cooling loads (KWH)	27735	27735	27735	27735	27731
North-west	Average daylight factor (%)	1,546	1,904	2,182	2,171	2,116
	Heating and cooling loads (KWH)	27735	27735	27735	27735	27732

Energy consumption for heating and cooling was found to be almost constant while varying the window lintel level height, but changeable according to the orientation change, as shown in the diagram in Figure 6.36. Where the optimum orientation was found to be toward the south in terms of achieving the optimal daylighting and minimal energy consumption as well. All the results did not meet daylight requirements, even the optimum ones.

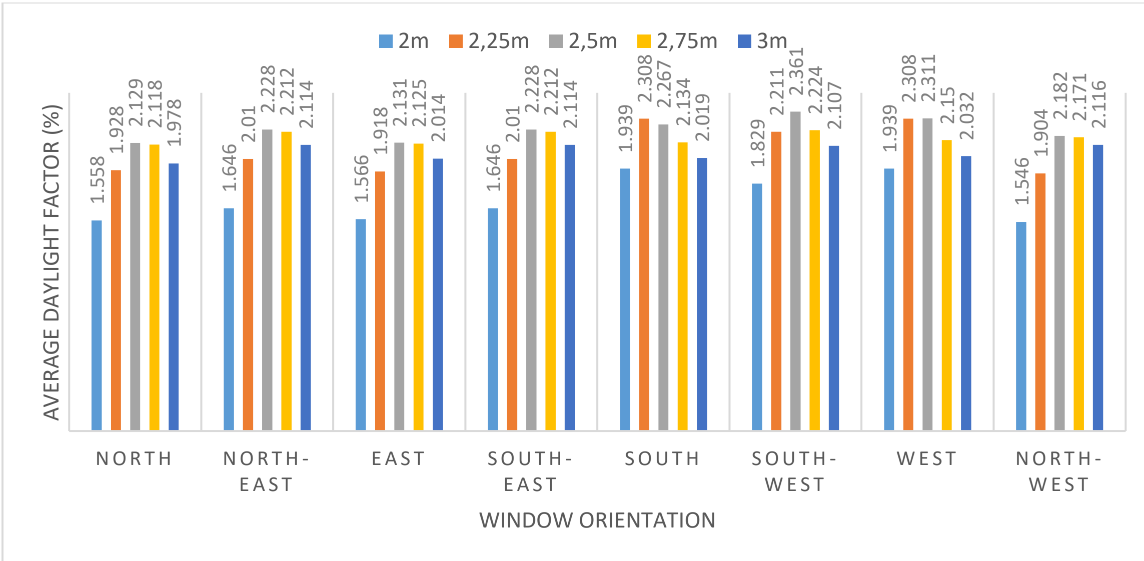


Figure 6.35: Simulation results of average daylight factor of the two-bed-ICU room at all orientations according to the change of window lintel level height.

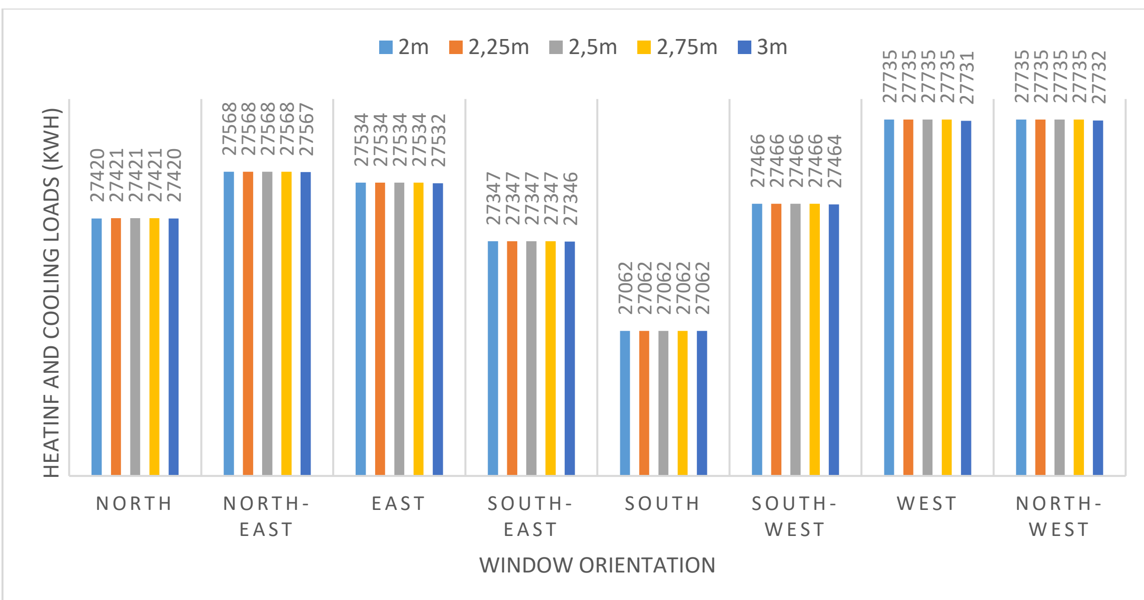


Figure 6.36: Simulation results of the annual heating and cooling loads of the two-bed-ICU room at all orientations according to the change of window lintel level height

6.3.4.2. Window to Wall Ratio

Because the values of the average daylight factor resulted from the previous simulation process when the window to wall ratio was assumed 30%, were below the acceptable value, window to wall ratio was tested starting from 30% up to 50%, while values below that were excluded, as shown in Table 6.43. The simulation was conducted such that window lintel level height was 2.5m at north, north-east, east, south-west and west orientations, 2.25m for south orientation and 2.75m for south-east orientation, light reflectance value of the inner surfaces of the walls was 0,5 no shading devices were used.

Table 6.43: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at all orientations according to the change of window to wall ratio.

Window orientation	Window to wall ratio	30%	40%	50%
North	Average daylight factor (%)	2,129	2,792	3,365
	Heating and cooling loads (KWH)	27421	27506	27593
North-East	Average daylight factor (%)	2.228	2,905	3,417
	Heating and cooling loads (KWH)	27568	27705	27843
East	Average daylight factor (%)	2,131	2,810	3,352
	Heating and cooling loads (KWH)	27534	27701	27878
South-East	Average daylight factor (%)	2,225	2,848	3,473
	Heating and cooling loads (KWH)	27347	27476	27627
South	Average daylight factor (%)	2,308	3,072	3,738
	Heating and cooling loads (KWH)	27062	27136	27251
South-West	Average daylight factor (%)	2,361	3,099	3,632
	Heating and cooling loads (KWH)	27466	27654	27884
West	Average daylight factor (%)	2,311	3,066	3,714
	Heating and cooling loads (KWH)	27735	27989	28264
North-west	Average daylight factor (%)	2,182	2,856	3,354
	Heating and cooling loads (KWH)	27735	27931	28134

The significant impact of raising the window to wall ratio on the daylight factor and the heating and cooling loads are shown in Figure 6.37 and 6.38 respectively.

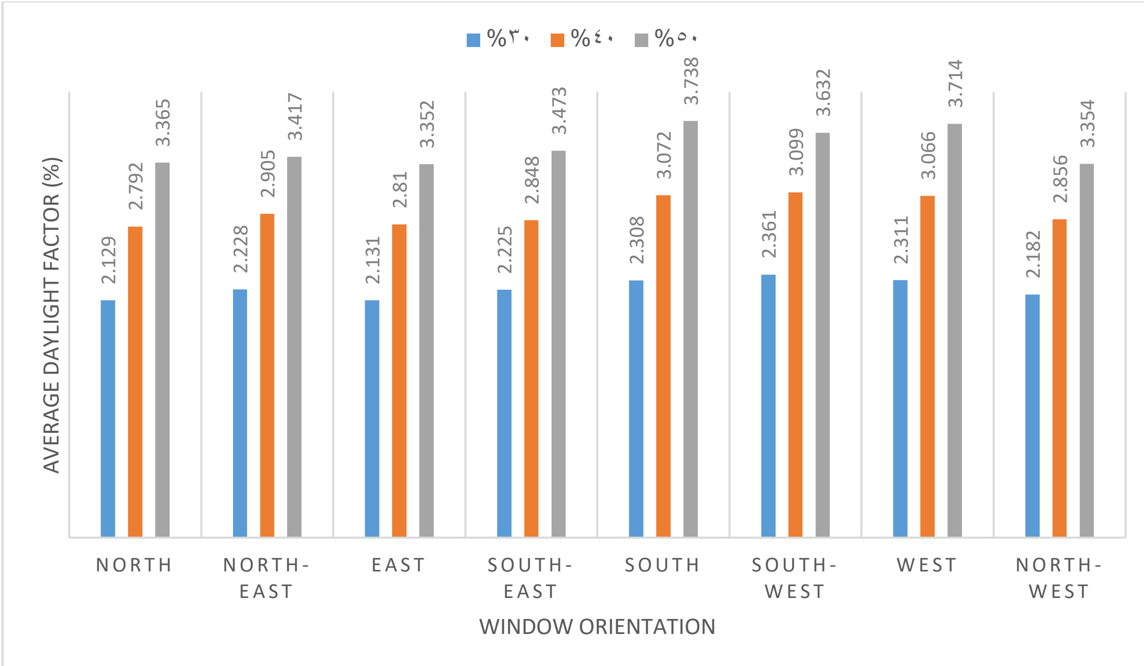


Figure 6.37: Simulation results of average daylight factor of the two-bed ICU room at all orientations according to the change of window to wall ratio.

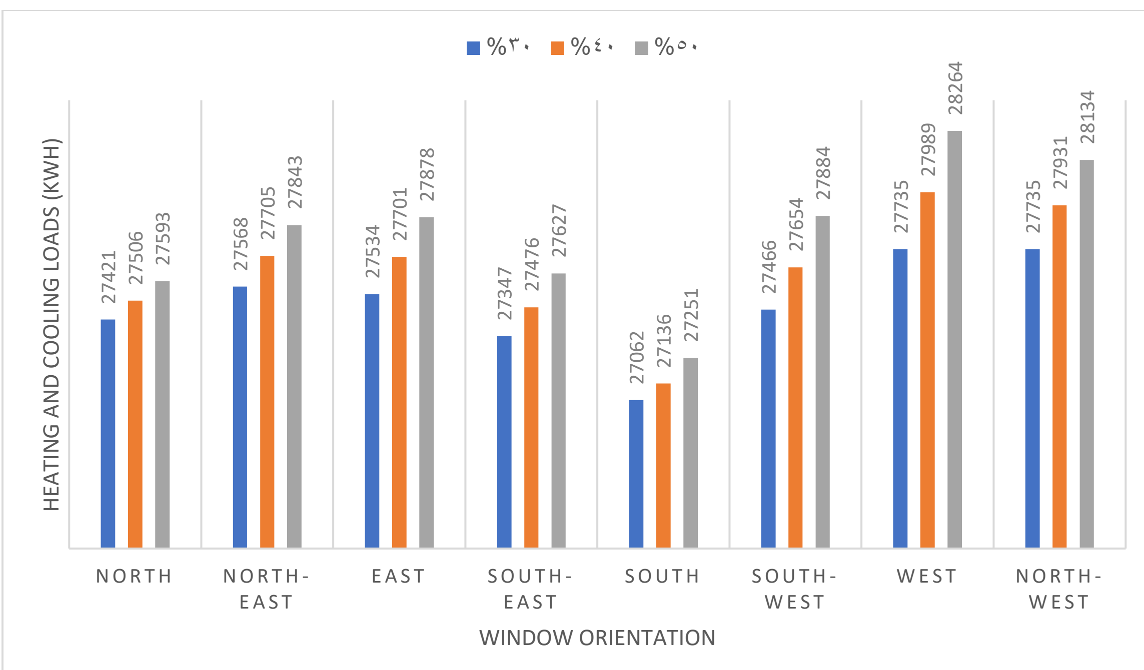


Figure 6.38: Simulation results of the annual heating and cooling loads of the two-bed ICU room at all orientations according to the change of window to wall ratio.

6.3.4.3. Shading Device

As in the single room optimization process, overhang shading device was proposed for south-oriented window, side fins were proposed for north-east, east, west and north-west-oriented windows and a combination of both was proposed for south-east and south-west oriented windows in the two-bed ICU room. Simulation results are in the following:

6.3.4.3.1. South

The simulation process was conducted to the studied two-bed room when its single window was oriented to the south, its lintel level height was 2,25m and window to wall ratio was 40%. Results, shown in Table 6.44, found that an overhang shading device would reduce the average daylight factor below the required value, even if its depth is 10% of the window height. Therefore, no shading device should be used at the southern window if the window to wall ratio is 40%.

Table 6.44: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south orientation according to the change of overhang shading device's depth *

Horizontal shading device depth (as a percentage of window height)	10%	20%	30%	40%	50%
Average daylight factor	2,826	2,568	2,328	2,113	1.934
Heating and cooling loads (KWH)	27069	27023	27003	27004	27000

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.25m, 40%, 0,5 and 1,5m respectively and no vertical shading device was used.

However, the results of the studied room with a change of window to wall ratio to be 50% and the addition of an overhang shading device with a depth of 20% of window height can enhance the daylight factor and reduce the energy consumption as well. This provides a daylight factor of 3,113% and energy consumption of 27088KWH rather than 3,072% and 27136KWH if the window to wall ratio is 40% and no shading device is used. This can be seen in Table 6.45, where simulation trials were conducted when the window to wall ratio was 50% and the overhang shading device depth was 20% of the window height.

Table 6.45: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south orientation according to the change of overhang shading device's depth *

Horizontal shading device depth (as a percentage of window height)	10%	20%	30%	40%	50%
Average daylight factor	3,426	3,113	2,814	2,533	2,320
Heating and cooling loads (KWH)	27173	27088	27043	27023	37024

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.25m, 50%, 0,5 and 1,5m respectively and no vertical shading device was used.

6.3.4.3.2. North-East

Simulation results of the north-east oriented window are shown in Table 6.46, it was found that the vertical shading device is effective in terms of reducing heating and cooling loads when its depth changes to 30% of window width. While a depth of more than 30% was found to be inefficient, as the reduction of the heating and cooling loads did not exceed 6 KWH when increasing the vertical shading device's depth by 10% of the window width.

Table 6.46: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at north-east orientation according to the change of the vertical shading device's depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3,375	3,307	3,231	3,197	3,196	3,200
Heating and cooling loads (KWH)	27815	27798	27787	27781	27776	27772

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 50%, 0,5 and 1,5m respectively and no horizontal shading device was used.

6.3.4.3.3. East and West

Side fins were found to be ineffective in reducing heating and cooling loads of more than 5 KWH as a result of increasing their depth by 10% of window width in east and west oriented windows. Simulation results of the vertical shading device depth in east and west orientations are shown in Table 6.47 and 6.48.

Table 6.47: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at east orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3,330	3.259	3,200	3,171	3,148	3,158
Heating and cooling loads (KWH)	27880	27878	27876	27875	27872	27870

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 50%, 0,5 and 1,5m respectively and no horizontal shading device was used.

Table 6.48: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at west orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3,015	2,938	2,891	2,869	2,875	2,825
Heating and cooling loads (KWH)	27987	27982	27977	27974	27971	27968

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 40%, 0,5 and 1,5m respectively and no horizontal shading device was used.

6.3.4.3.4. North-West

Simulation results of the north-west orientation show that the vertical shading device significantly minimizes the heating and cooling loads of the studied two-bed ICU room. As the higher depth of the vertical device of 10% of window width, the lower energy consumption for more than 10 KWH. The lowest amount of energy consumption was recorded at a depth of 60% of window width. The results are shown in Table 6.49.

Table 6.49: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at north-west orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3,352	3,266	3,241	3,241	3,210	3,188
Heating and cooling loads (KWH)	28095	28068	28050	28035	28022	28010

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 50%, 0,5 and 1,5m respectively and no horizontal shading device was used.

6.3.4.3.5. South-East

The south-east and south-west orientations were tested using the two methods used in the single room optimization. In order to apply the first method, a vertical shading device was tested first, then the optimum result was used in the next optimization of the horizontal shading device. The resulted average daylight factor and heating and cooling loads are in Table 6.50 and 6.51, it was found that the optimum depth of the vertical shading device is 30% of window width, while more than this depth would not be significant, while no horizontal shading device should be used with it, since the average daylight factor would be below the required value.

Table 6.50: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south-east orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3,369	3,320	3,271	3,231	3,228	3,193
Heating and cooling loads (KWH)	27598	27579	27567	27559	27554	27550

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.75m, 50%, 0,5 and 1,5m respectively and no horizontal shading device was used.

Moreover, the addition of an overhang shading device with a depth of 10% of the window height would reduce the energy consumption. However, a depth of more than 10% would result in inadequate daylight in the room.

Table 6.51: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south- west orientation according to the change of the horizontal shading device depth *

shading device depth (as a percentage of window height)	10%	20%	30%	40%	50%
Average daylight factor (%)	3,003	2,751	2,560	2,301	2,053
Heating and cooling loads (KWH)	27520	27461	27414	27358	27318

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.75m, 50%, 0,5 and 1,5m respectively and a vertical shading device with a depth of 30% of window width was used.

The same result was concluded when repeating the simulation process of the south-east orientation when applying the second method (overhang shading device was optimized before the vertical). Therefore, a vertical shading device with a depth of 30% of window width and a horizontal shading device with a depth of 10% of window height is the optimum combination for south-east oriented windows. Table 6.52 and 6.53 show the simulation results of the second method of shading device of the south-east orientation.

Table 6.52: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south- east orientation according to the change of the horizontal shading device depth *

shading device depth (as a percentage of window height)	10%	20%	30%	40%	50%
Average daylight factor (%)	3,200	2,892	2,616	2,400	2,207
Heating and cooling loads (KWH)	27579	27497	27431	27380	27345

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.75m, 50%, 0,5 and 1,5m respectively and no vertical shading device was used.

Table 6.53: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south-east orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%
Average daylight factor (%)	3,086	3,029	3,003	2,978	2,944
Heating and cooling loads (KWH)	27551	27532	27520	27513	27508

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.75m, 50%, 0,5 and 1,5m respectively and a horizontal shading device of a depth of 10% of window height was used.

6.3.4.3.6. South-West

As for the south-west orientation, it was found that the vertical shading device with a depth of 10% of window width can reduce the energy consumption by 47KWH, with keeping the average daylight factor within the required, while more than 10% or the addition of a horizontal shading device would decrease the daylight factor below the acceptable value, although it is significant in reducing the energy consumption, as shown in Table 6.54 and 6.55, where simulation results of the first method are. Whereas, Table 6.56 shows that an overhang shading device should not be used in this orientation, since it would reduce the daylight factor below the acceptable value, even if it is used alone and with a depth of 10% of the window height.

Table 6.54: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south-west orientation according to the change of the vertical shading device's depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3,025	2,945	2,902	2.901	2,862	2,842
Heating and cooling loads (KWH)	27607	27568	27540	27527	27510	27503

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 40%, 0,5 and 1,5m respectively and no horizontal shading device was used.

Table 6.55: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south- west orientation according to the change of the horizontal shading device's depth *

shading device depth (as a percentage of window height)	10%	20%	30%	40%	50%
Average daylight factor (%)	2,767	2,471	2,232	1,993	1,791
Heating and cooling loads (KWH)	27537	27493	27428	27377	27339

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 40%, 0,5 and 1,5m respectively and a vertical shading device of a depth of 10% of window width was used.

Table 6.56: Simulation results of the average daylight factor and the annual heating and cooling loads of the two-bed ICU room at south- west orientation according to the change of the horizontal shading device's depth *

shading device depth (as a percentage of window height)	10%	20%	30%	40%	50%
Average daylight factor (%)	2,766	2,566	2,339	2,106	1,919
Heating and cooling loads (KWH)	27588	27537	27469	27414	27374

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 40%, 0,5 and 1,5m respectively and no vertical shading device was used.

The concluded optimum values of window lintel level height, window to wall ratio and shading device depth that related to each orientation for the two-bed ICU room are shown in Figure 6.39 below.

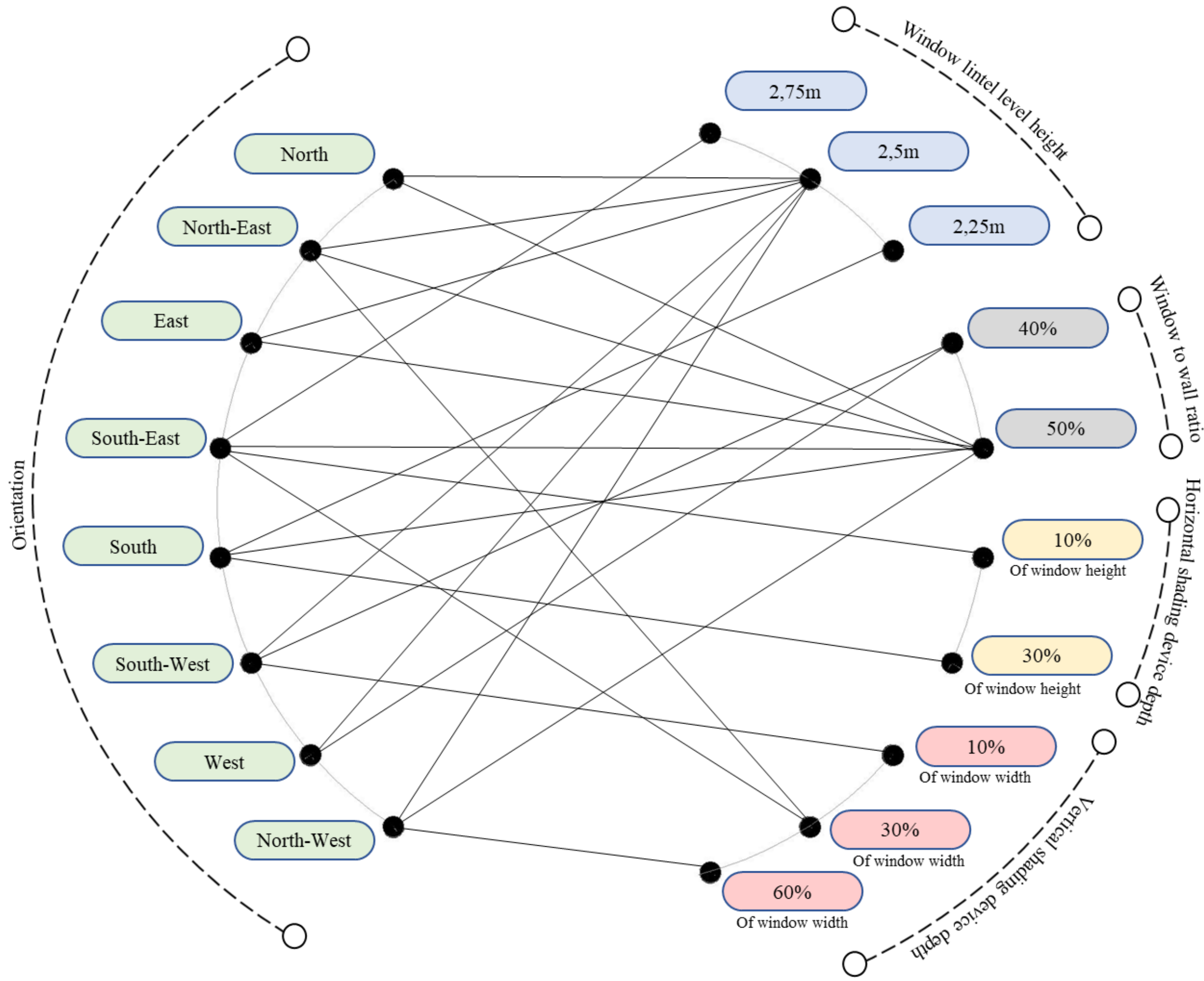


Figure 6.39: The optimum values of window lintel level height, window to wall ratio and shading device depth that related to each orientation for the two-bed ICU room

6.3.5. A Patient Area Within an ICU Ward.

A room of 4,7m depth, 4,3m width and 3m height was modeled to represent a patient area within an ICU ward. The side curtains were represented by walls with a light reflectance value of 0.57, which is the value of cream-colored fabric (Panaz, 2020) while the reflectance value of the wall opposite the external wall was assumed 0 to represent the continuity of the space.

6.3.5.1. Window Lintel Level Height:

Table 6.57: Simulation results of the average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at all orientations according to the change of window lintel level height *

Window orientation	Window lintel level hight (m)	2	2.25	2.5	2.75	3
North	Average daylight factor (%)	2,401	2,948	3,205	3,134	2,938
	Heating and cooling loads (KWH)	14063	14063	14063	14064	14063
	Average daylight factor (%)	2,624	3,230	3,498	3,276	3,098
North-East	Heating and cooling loads (KWH)	14202	14202	14202	14202	14201
East	Average daylight factor (%)	2,381	2,930	3,215	3,142	2,898
	Heating and cooling loads (KWH)	14207	14207	14207	14207	14205
South-East	Average daylight factor (%)	2,813	3,417	3,525	3,261	2,992
	Heating and cooling loads (KWH)	14057	14057	14057	14057	14055
South	Average daylight factor (%)	2,965	3,534	3,418	3,082	2,847
	Heating and cooling loads (KWH)	13834	13834	13834	13834	13833
South-West	Average daylight factor (%)	2,465	3,016	3,414	3,286	2,999
	Heating and cooling loads (KWH)	14172	14172	14172	14172	14169
West	Average daylight factor (%)	2,980	3,575	3,515	3,141	2,890
	Heating and cooling loads (KWH)	14392	14392	14392	14391	14388
North-west	Average daylight factor (%)	2,782	3,383	3,508	3,266	2,989
	Heating and cooling loads (KWH)	14349	14349	14349	14349	14347

Window lintel level height was tested for the patient area for the 8 orientations, and the results are shown in Table 6.57. It was found that the highest values of the average daylight factor were recorded at a window lintel level height of 2.5m for the north, north-east, east, south-east, south-west, west and north-west-oriented windows and 2,25 for the south and west-oriented windows. This can be noticed from Figure 6.40 below. On the other hand, there was no significant change in energy consumption for heating and cooling as a consequence of the change in window level. While the changes as a result of orientation were significant, as the south is the best orientation in terms of providing the optimal daylighting and energy consumption together as shown in Figure 6.41.

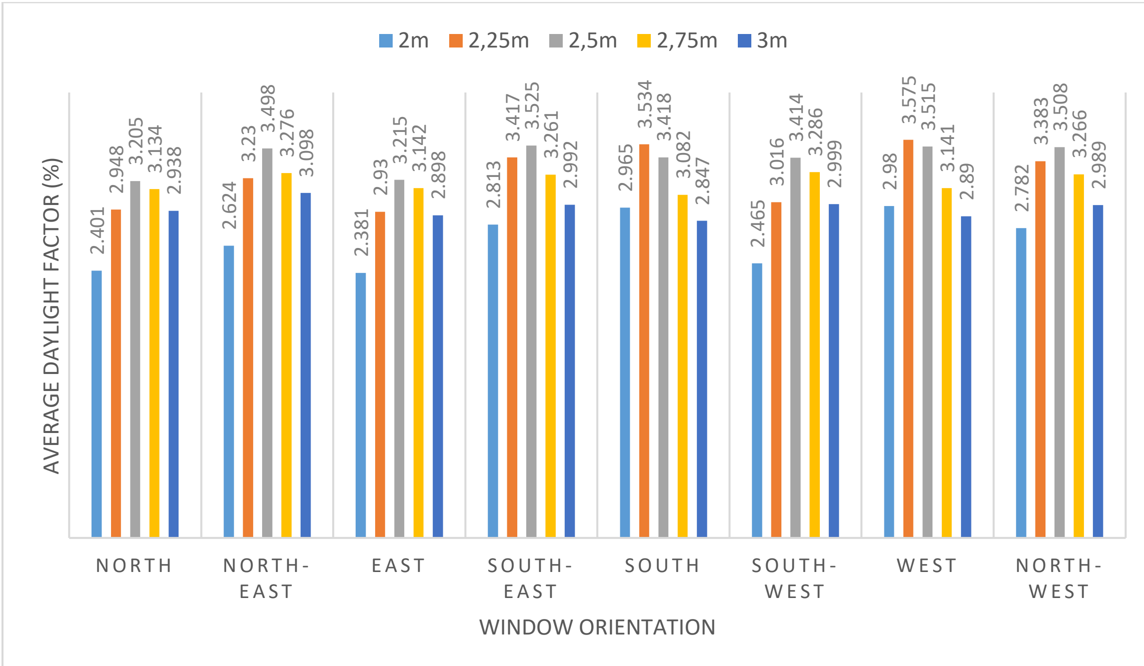


Figure 6.40: Simulation results of average daylight factor of the patient area within an ICU ward at all orientations according to the change of window lintel level height.

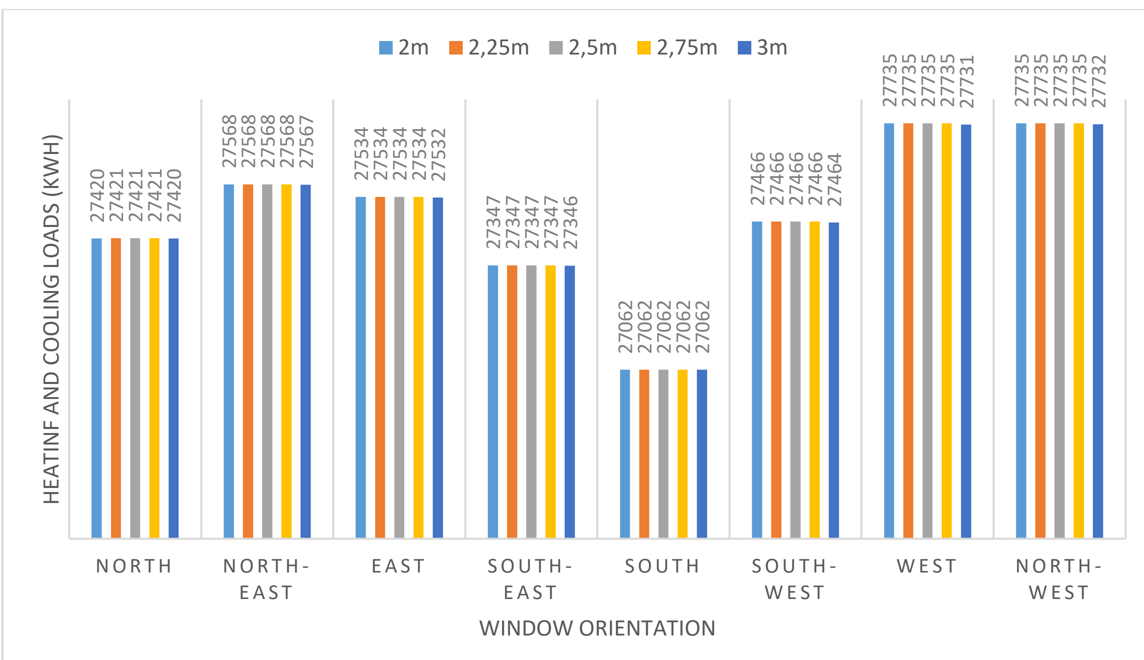


Figure 6.41: Simulation results of the annual heating and cooling loads of the patient area within an ICU ward at all orientations according to the change of window lintel level height

6.3.5.2. Window to Wall Ratio

Window to wall ratio was tested for the 8 orientations with keeping the optimum window level resulted from the previous optimization constant for each orientation, as window lintel level was assumed 2,25m for south and west oriented window and 2,5m for the other orientations. As shown in Table 6.58, it was found that the optimum window to wall ratio for all orientation is 30%.

As the previously studied models, the influence of raising the window to wall ratio is significant in increasing the daylight factor and reducing the heating and cooling loads. This can be noticed in Figure 6.42 and 6.43.

Table 6.58: Simulation results of the average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at all orientations according to the change of window to wall ratio.

Window orientation	Window to wall ratio	10%	20%	30%	40%	50%
North	Average daylight factor (%)	0,881	2,057	3,205	4,231	5,073
	Heating and cooling loads (KWH)	13928	13994	14063	14134	14207
North-East	Average daylight factor (%)	0,950	2,268	3,498	4,612	5,411
	Heating and cooling loads (KWH)	13980	14088	14202	14316	14431
East	Average daylight factor (%)	0,872	2,080	3,215	4,276	5,075
	Heating and cooling loads (KWH)	13947	14067	14207	14356	14519
South-East	Average daylight factor (%)	0,967	2,282	3,525	4,608	5,484
	Heating and cooling loads (KWH)	13893	13952	14057	14190	14351
South	Average daylight factor (%)	0,956	2,261	3,534	4,705	5,449
	Heating and cooling loads (KWH)	13785	13773	13834	13947	14110
South-West	Average daylight factor (%)	0,943	2,205	3,414	4,508	5,406
	Heating and cooling loads (KWH)	13912	14010	14172	14378	14631
West	Average daylight factor (%)	0,972	2,275	3,575	4,733	5,756
	Heating and cooling loads (KWH)	13989	14172	14392	14630	14888
North-west	Average daylight factor (%)	0,967	2,287	3,508	4,564	5,444
	Heating and cooling loads (KWH)	14022	14180	14349	14520	14697

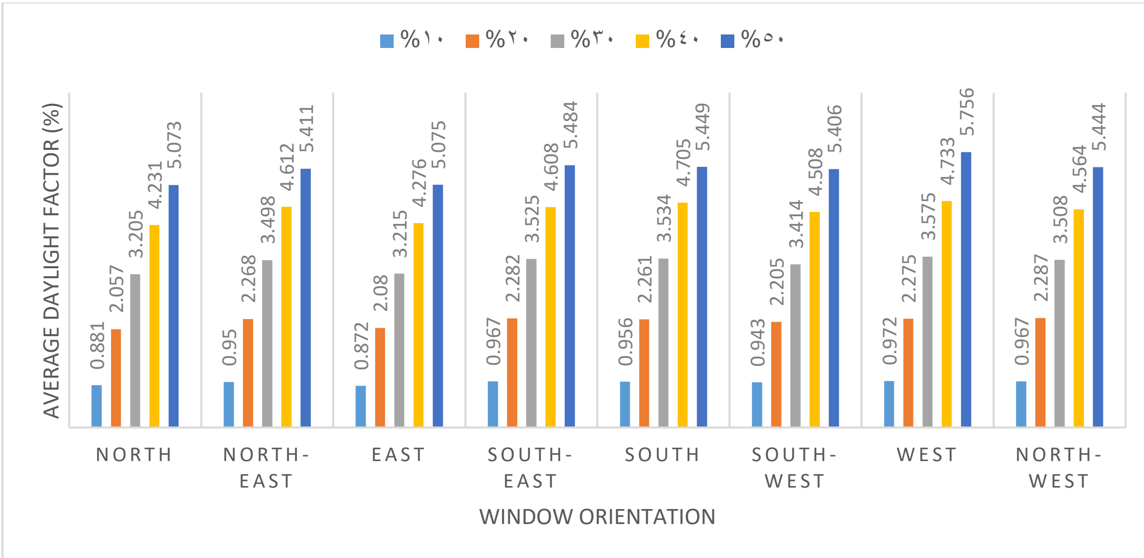


Figure 6.42: Simulation results of average daylight factor of the patient area within an ICU ward at all orientations according to the change of window to wall ratio.

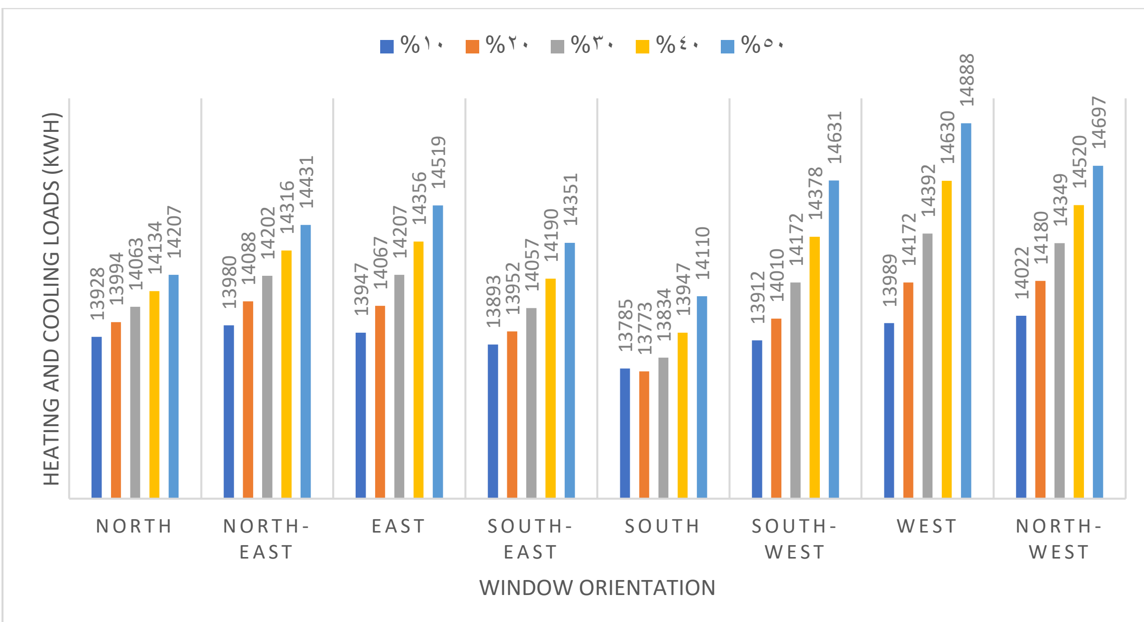


Figure 6.43: Simulation results of the annual heating and cooling loads of the patient area within an ICU ward at all orientations according to the change of window to wall ratio.

6.3.5.3. Shading Device

6.3.5.3.1. South

Simulation results shown in Table 6.59 show that an overhang shading device of a depth of 10% of window height would reduce the energy consumption for heating and cooling by

43KWH (from 13834KWH to 13791KWH) with keeping the average daylight factor within the required value. However, despite a depth of more than 10% of window height had also a significant impact on energy consumption, it would reduce the daylight factor below the required value.

Table 6.59: Simulation results of the average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south orientation according to the change of overhang shading device's depth *

Horizontal shading device depth (as a percentage of window height)	10%	20%	30%	40%	50%
Average daylight factor	3,325	2,931	2,647	2,418	2,226
Heating and cooling loads (KWH)	13791	13762	13749	13749	13758

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of the external wall and window height were assumed 2.25m, 30%, 0,5 and 1,5m respectively and no vertical shading device was used.

6.3.5.3.2. North-East

From simulation results shown in Table 6.60, it was found that a vertical shading device of a depth of 20% of window width can significantly reduce the heating and cooling loads, while the reduction in the loads becomes insignificant (less than 10 KWH) when the depth is 30% of window width or more.

Table 6.60: Simulation results of the average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at north-east orientation according to the change of the vertical shading device's depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3.393	3.251	3,131	3,049	3,016	2,959
Heating and cooling loads (KWH)	14186	14173	14164	14157	14152	14147

* Window lintel level height, window to wall ratio, light reflectance value of inner surface of the external wall and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and no horizontal shading device was used.

6.3.5.3.3. East and West

Side fins were found ineffective in reducing the heating and cooling loads, as the reduction of it when raising the depth of 10% of window width did not exceed 4 KWH for both orientations. This can be noticed in Table 6.61 and 6.62.

Table 6.61: Simulation results of the average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at east orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3,088	2,976	2,859	2,813	2,749	2,688
Heating and cooling loads (KWH)	14210	14213	14215	14217	14218	14218

* Window lintel level height, window to wall ratio, light reflectance value of inner surface of the external wall and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and no horizontal shading device was used.

Table 6.62: Simulation results of the average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at west orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3,422	3,268	3,161	3,077	3,018	2,977
Heating and cooling loads (KWH)	14388	14386	14383	14382	14381	14380

* Window lintel level height, window to wall ratio, light reflectance value of inner surface of the external wall and window height were assumed 2.25m, 30%, 0,5 and 1,5m respectively and no horizontal shading device was used.

6.3.5.3.4. North-West

Simulation results of the north-west orientation show that the higher depth of the vertical device of 10% of the window width, the lower energy consumption by more than 10 KWH. While a depth of more than 40% of the window width resulted in an unacceptable value of the average daylight factor. Therefore, the optimum depth of the vertical shading device is that equivalent to 40% of the window width. As shown in Table 6.63.

Table 6.63: Simulation results of the average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at north-west orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3,381	3,248	3,141	3,066	2,994	2,981
Heating and cooling loads (KWH)	14328	14309	14294	14282	14270	14259

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and no horizontal shading device was used.

6.3.5.3.5. South-East

Shading devices depth in the south-east and south-west orientations were optimized using the two methods used in the previous models. In the first method, the vertical shading device was tested first, then the resulted optimum depth was used as an input in the next optimization of the horizontal shading device. From the results in Table 6.64 and 6.65, it was found that the optimum depth of the vertical shading device resulted from the first method is 20% of the window width, while more than this depth would not be significant and no horizontal shading device should be used with it because the average daylight factor would be below the required value. This reduced energy consumption by 18KWH.

Table 6.64: Simulation results of the average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south-east orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3,454	3,288	3,180	3,077	3,024	3,015
Heating and cooling loads (KWH)	14051	14039	14030	14024	14018	14009

* Window lintel level height, window to wall ratio, light reflectance value of inner surface of the wall and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and no horizontal shading device was used.

Table 6.65: Simulation results of the average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south- west orientation according to the change of the horizontal shading device depth *

shading device depth (as a percentage of window height)	10%	20%	30%	40%	50%
Average daylight factor (%)	2,986	2,632	2,355	2,099	1,902
Heating and cooling loads (KWH)	14006	13974	13950	13926	13919

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and a vertical shading device with a depth of 20% of window width was used.

On the other hand, in the second method, the horizontal shading device was optimized first, then the addition of a vertical shading device was tested. This process resulted in a combination of a horizontal shading device with a depth of 10% of the window height and a vertical with a depth of 10% of the window width. This reduced the heating and cooling loads by 47 KWH (from

14057KWH to 14010KWH), which is better than the first method. As shown in Table 6.66 and 6.67.

Table 6.66: Simulation results of the average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south- east orientation according to the change of the horizontal shading device depth *

shading device depth (as a percentage of window height)	10%	20%	30%	40%	50%
Average daylight factor (%)	3,279	2,975	2,679	2,446	2,261
Heating and cooling loads (KWH)	14022	13988	13961	13942	13932

* Window lintel level height, window to wall ratio, light reflectance value of inner surface of the external wall and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and no vertical shading device was used.

Table 6.67: Simulation results of the average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south-east orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%
Average daylight factor (%)	3,148	2,986	2,869	2,800	2,747
Heating and cooling loads (KWH)	14010	14006	13990	13985	13980

* Window lintel level height, window to wall ratio, light reflectance value of inner surfaces of walls and window height were assumed 2. 5m, 30%, 0,5 and 1,5m respectively and a horizontal shading device of a depth of 10% of window height was used.

6.3.5.3.6. South-West

The 2 methods were also applied in the south-west-oriented window: the first resulted in a vertical shading device with a depth of 30% of window width without using a horizontal one, this can reduce the energy consumption by 85KWH. While the second resulted in a combination of a horizontal shading device with a depth of 10% of the window height and a vertical with a depth of 10% of the window width, which can reduce the energy consumption by 58KWH. The simulation results of the first method are shown in Table 6.68 and 6.69, while the results of the second method are in Table 6.70 and 6.71.

Table 6.68: Simulation results of the average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south-west orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%	60%
Average daylight factor (%)	3,324	3,182	3,058	2,989	2,926	2,880
Heating and cooling loads (KWH)	14140	14111	14087	14069	14056	14059

* Window lintel level height, window to wall ratio, light reflectance value of inner surface of the external wall and window height were assumed 2.5m, 30%, 0,5 and 1,5m respectively and no horizontal shading device was used.

Table 6.69: Simulation results of the average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south- west orientation according to the change of the horizontal shading device depth *

shading device depth (as a percentage of window height)	10%	20%	30%	40%	50%
Average daylight factor (%)	2,784	2,474	2,204	1,963	1,720
Heating and cooling loads (KWH)	14043	13999	13964	13938	13929

* Window lintel level height, window to wall ratio, light reflectance value of inner surface of the external wall and window height were assumed 2.5m, 40%, 0,5 and 1,5m respectively and a vertical shading device of a depth of 30% of window width was used.

Table 6.70: Simulation results of the average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south- west orientation according to the change of the horizontal shading device depth *

shading device depth (as a percentage of window height)	10%	20%	30%	40%	50%
Average daylight factor (%)	3,150	2,860	2,586	2,380	2,174
Heating and cooling loads (KWH)	14125	14097	14052	14020	13995

* Window lintel level height, window to wall ratio, light reflectance value of inner surface of the external wall and window height were assumed 2.5m, 40%, 0,5 and 1,5m respectively and no vertical shading device was used.

Table 6.71: Simulation results of the average daylight factor and the annual heating and cooling loads of the patient area within an ICU ward at south-west orientation according to the change of the vertical shading device depth *

Vertical shading device depth (as a percentage of window width)	10%	20%	30%	40%	50%
Average daylight factor (%)	3,021	2,876	2,783	2,701	2,672
Heating and cooling loads (KWH)	14114	14085	14062	14044	14032

* Window lintel level height, window to wall ratio, light reflectance value of inner surface of the external wall and window height were assumed 2. 5m, 30%, 0,5 and 1,5m respectively and a horizontal shading device of a depth of 10% of window height was used.

The concluded optimum values of window lintel level height, window to wall ratio and shading device depth that related to each orientation for the ICU single/isolated room are shown in Figure 6.44.

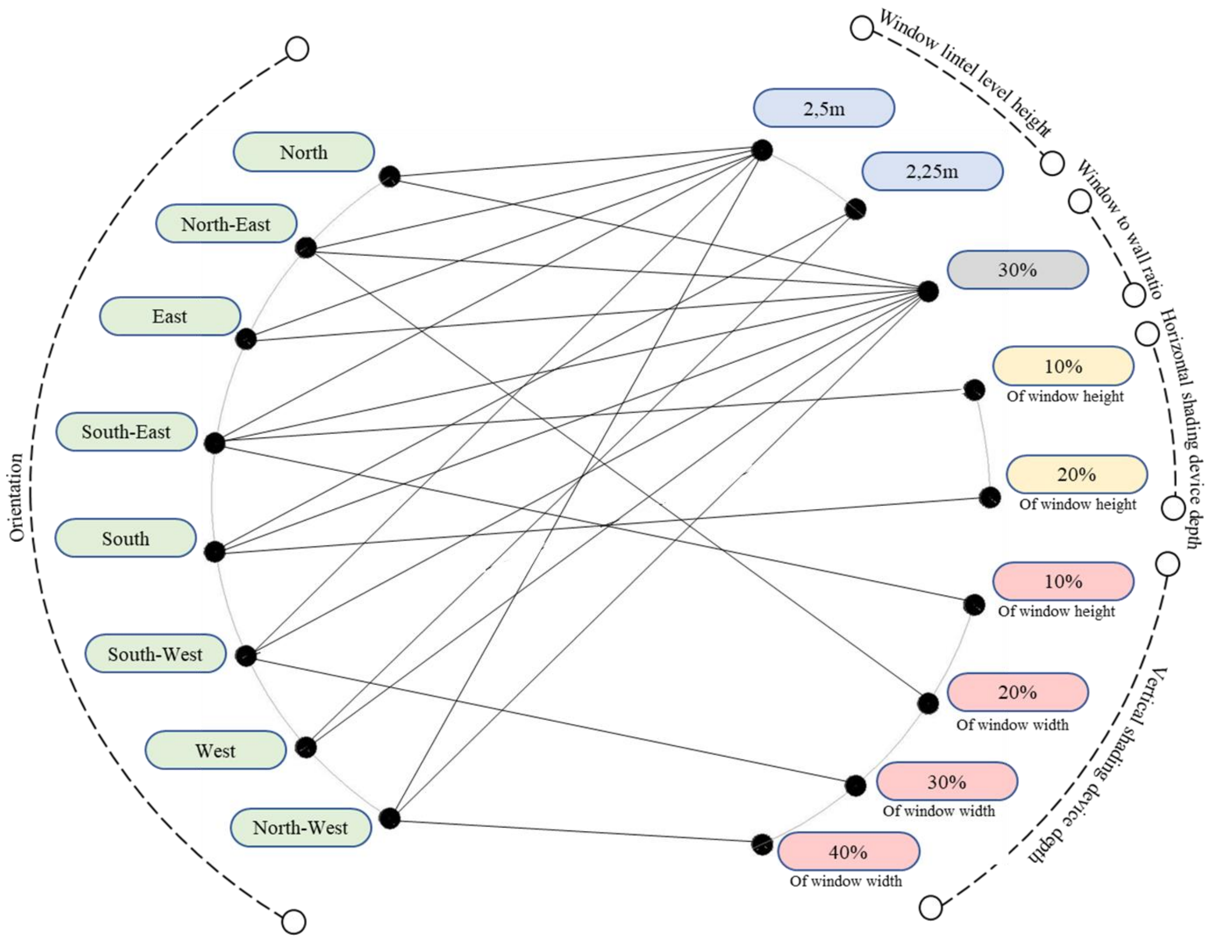


Figure 6.44: The optimum values of window lintel level height, window to wall ratio and shading device depth that related to each orientation for a patient area within an ICU ward

6.4. Enhancement of the Studied ICUs

A healing environment in the ICU of the studied hospitals can be developed by conducting modification of beds layout and window size and through the addition of shading devices. Rooms dimensions were modified as well, to comply with the minimum required patient area mentioned in Chapter 3, Section 3.2.2. while the values of the window to wall ratio, window lintel level height and shading devices' depth were based on the results of the optimization process in section 6.2 in this chapter.

6.4.1. Alahli Hospital

The design modification of the ICU of Alahli Hospital was mainly based on changing beds' layout to be parallel with the external walls to ensure patient access to view, enlarging patients' areas to meet the standard requirements, increasing windows size and adding shading devices. The original design and the modified are in Figure 6.45. This modification led to having fewer beds but better daylight and access to view for all beds, as shown in Table 6.72 below.

Despite there are only twelve beds in the modified design instead of sixteen in the original, all beds have access to view as well as appropriate daylight and all patient areas are within the required.

Table 6.72: The differences between the ICU design of Alahli hospital before and after modification

	Number of beds	Number of beds that have the required area	Number of beds that have the required value of daylight factor	Number of beds that have access to outside views
Before modification	16	3	0	0
After modification	12	12	12	12

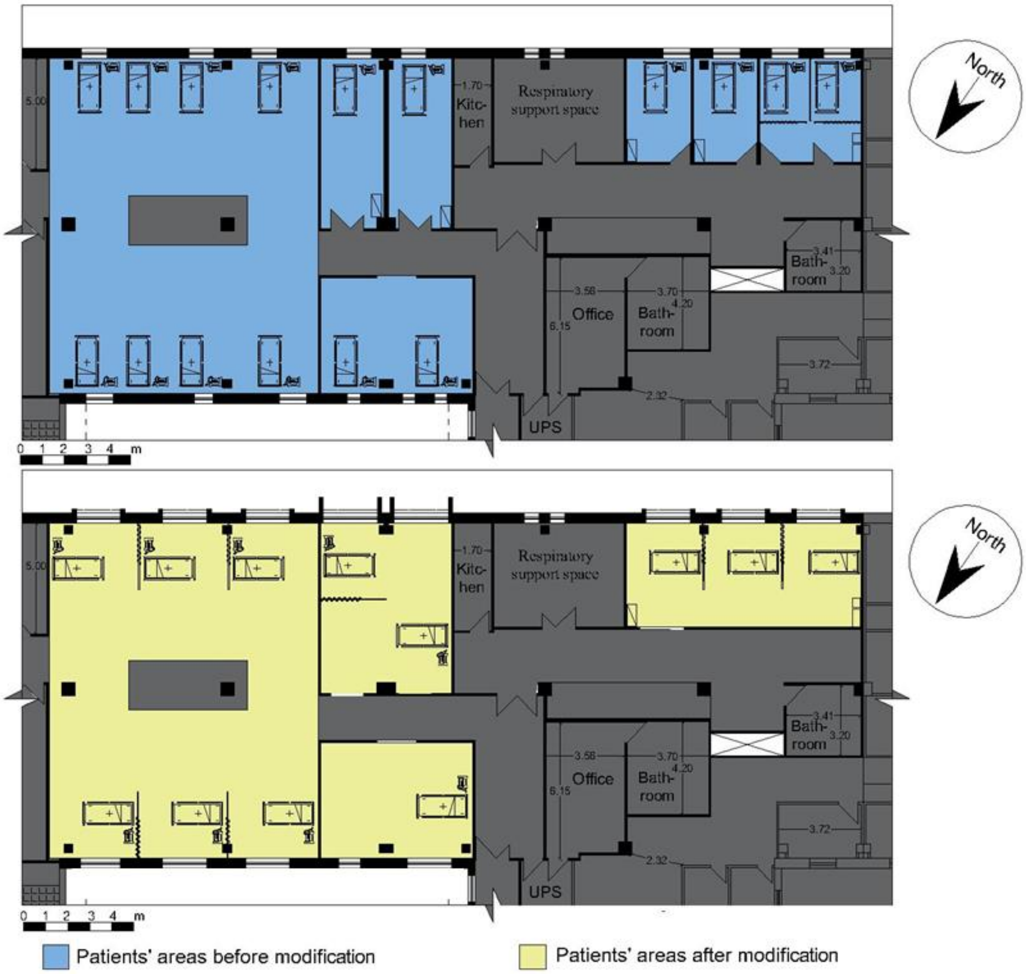


Figure 6.45: The floor plan of the ICU of Alahli Hospital before and after the modification.

6.4.2. Alia Governmental Hospital

The ICU of Alia Governmental Hospital contains a large number of beds (20 beds), but the area allocated for each bed does not meet the requirements. Therefore, the modification mainly targeted patients' areas and isolation rooms. This led to reducing the number of beds and moving the isolation rooms to the eastern side to avoid obstacles. The window to wall ratio was increased to reach 30% to increase the average daylight factor as required. The layout of the beds adjacent to windows was changed to be parallel to the walls to provide access to view. However, the other patients' areas, that have no windows, are recommended to be used only for unconscious patients. The ICU plan before and after the modification is in Figure 6.46.

Figure 6.46: The floor plan of the ICU of Alia Governmental Hospital before and after the modification.

The modified ICU has only 12 beds, 6 of them have daylight and access to view as presented in Table 6.73. While the others still have no windows. This is obviously due to the deep plan design.

Table 6.73: The differences between the ICU design of Alia Governmental hospital before and after modification

	Number of beds	Number of beds that have the required area	Number of beds that have the required value of daylight factor	Number of beds that have access to outside views
Before modification	20	0	0	0
After modification	12	11	6	6

6.4.3. Palestine Medical Complex

Conducting a design modification of the current ICU of Palestine Medical Complex is extremely challenging due to its location in the hospital, as it is surrounded by other built areas from three sides. Only the northern wall can include windows. Moreover, the area allocated for each patient is below the standard and there is no sufficient width for a corridor in front of beds.

Therefore, patients' areas were enlarged and beds' layout was modified to create a corridor, as shown in Figure 6.47.

The northern windows were enlarged to reach a window to wall ratio, window height and a window lintel level height of 30%, 1,5m and 2,5m respectively. Furthermore, the beds' layout of the northern side was rotated to be parallel to the external wall to provide access to view for patients.

The isolation room was replaced by a patient area within the open plan ward, since its area does not comply with isolation room dimensions and because all patients' areas of the unit expansion are in single and isolated rooms.

Figure 6.47: The floor plan of the ICU of Palestine Medical Complex before and after the modification.

Table 6.74: The differences between the ICU design of Palestine Medical Complex before and after modification

	Number of beds	Number of beds that have the required area	Number of beds that have the required value of daylight factor	Number of beds that have access to outside views
Before modification	12	0	0	0
After modification	7	7	2	2

The modification resulted in having seven ICU beds instead of twelve. But all of those seven beds have the required area. Whereas, due to the deep plan design, only two of them have the required daylight and access to view, as shown in Table 6.74. The five patients' areas, that do not have windows, are recommended to be used for unconscious patients.

6.4.4. Istishari Arab Hospital

Despite the southern patients' areas in the ICU of Istishari Arab Hospital achieve the required average daylight factor, the allocated areas for beds are below the required and the design does not achieve patients' access to view. Therefore, patients' areas were increased, beds' layout was modified to be parallel to the external walls and windows were modified in terms of size, distribution, and the used glass; as each bed area had at least an untinted window with a window to wall ratio of 30%. Furthermore, overhang shading devices were added to the southern windows to reduce the heating and cooling loads. Figure 6.48 shows the floor plan of the ICU before and after the modification.

This modification resulted in reducing the beds' number to be 7 instead of 10. While all daylight, access to view and area requirements are achieved, as presented in Table 6.75 below.

Table 6.75: The differences between the ICU design of Istishari Arab Hospital before and after modification

	Number of beds	Number of beds that have the required area	Number of beds that have the required value of daylight factor	Number of beds that have access to outside views
Before modification	10	0	4	0
After modification	7	7	7	7

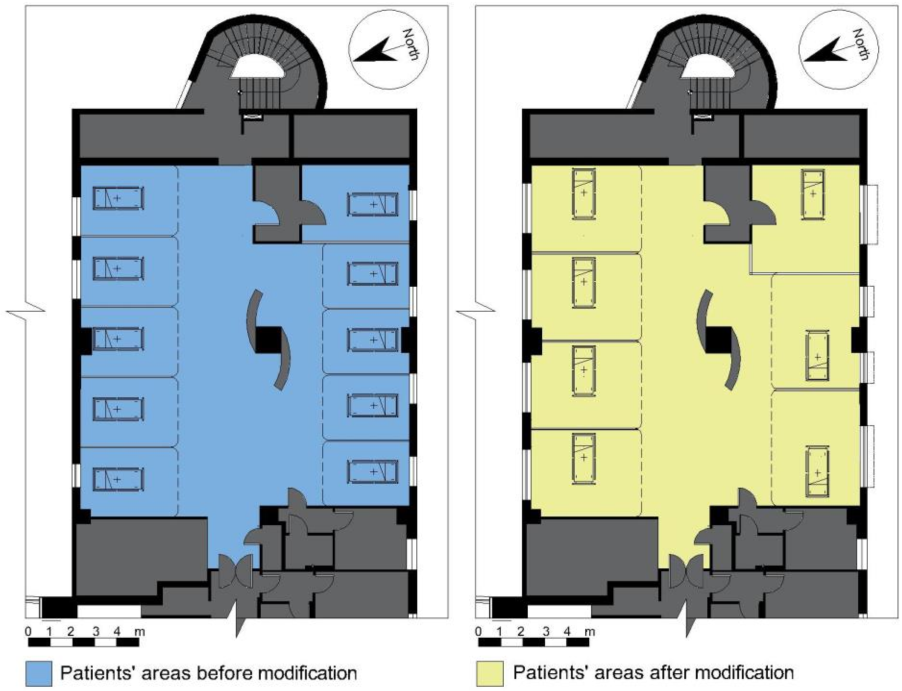


Figure 6.48: The floor plan of the ICU of Istishari Arab Hospital before and after the modification.

6.4.5. An-Najah National University Hospital

Figure 6.49: The floor plan of the surgical ICU of An-Najah National University Hospital before and after the modification.

The design of the surgical ICU of An-Najah National University Hospital was modified, such that patients' areas were enlarged to reach the required area, windows sizes were decreased, not tinted glass was used instead of the tinted and overhang shading devices were used to decrease heating and cooling loads. Furthermore, beds' layout was rotated to enhance patients' access to view. This process resulted in fewer beds, but better daylight and access to view.

The differences of the surgical ICU before and after the modification process are shown in Figure 6.49

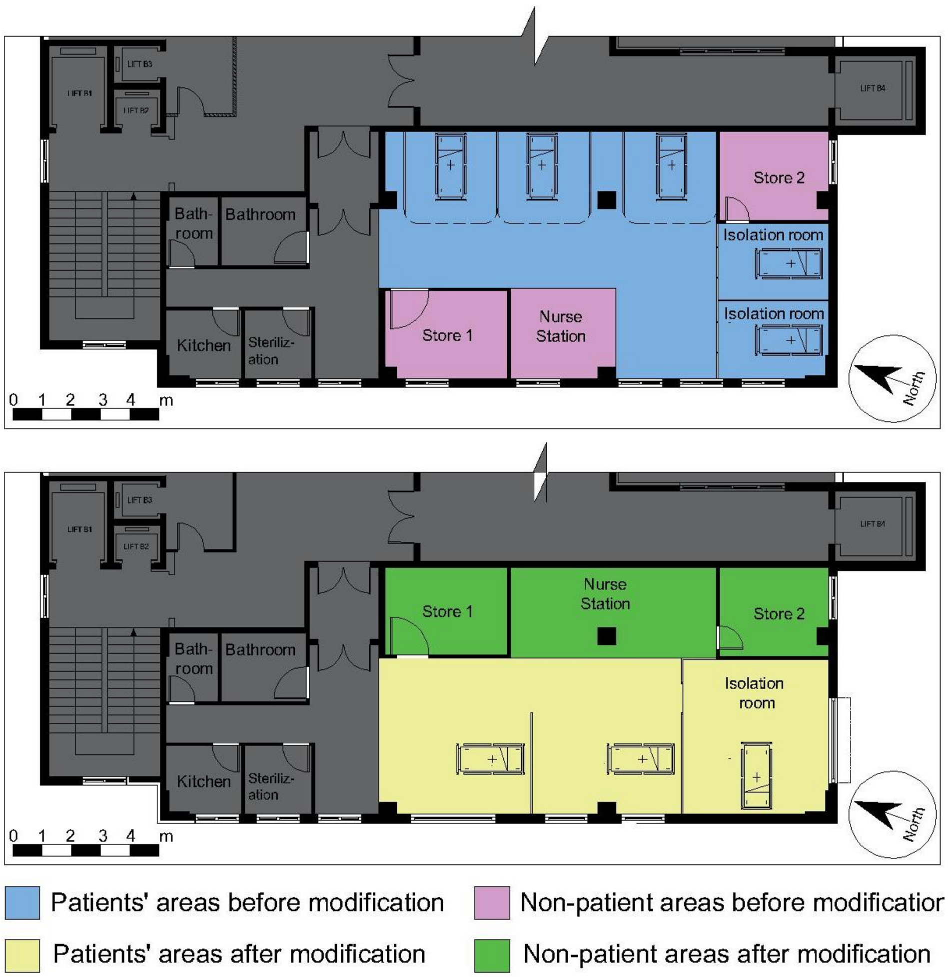


Figure 6.50: The floor plan of the medical ICU of An-Najah National University Hospital before and after the modification.

As for the medical ICU, the modification was quite different, due to its design, which makes non-patient areas next to the external wall, such as the nurse station and the store. Therefore, the modification process targeted non-patient areas as well as patients' areas as shown in Figure 6.50.

The nurse station and store 1 were moved to the western side of the ICU, and two patients' areas were arraigned in their place. The area of the isolation rooms was enlarged and replaced by one isolation room to achieve the appropriate room size. The door of store 2 was moved to be opened from the nurse station instead of the isolation room. And the window of the isolation room was moved to the southern external wall since it is the optimum orientation.

Despite the modified ICUs of An-Najah National University Hospital have fewer ICU beds, the daylight requirements and the access to view are achieved in all patients' areas. This can be noticed from Table 76 below.

Table 6.76: The differences between the ICU design of An-Najah National University Hospital before and after modification

	Number of beds	Number of beds that have the required area	Number of beds that have the required value of daylight factor	Number of beds that have access to outside views
Before modification	11	0	0	2
After modification	6	6	6	6

Chapter 7 - CONCLUSION

Daylight and access to view are essential for the mental, psychological and physical health of ICU patients. However, the designs of the ICUs in Palestine mainly don’t take this issue into account. Therefore, many related problems can be noticed as results of the lack of daylight and access to view, such as the high incidence of sleep problems and delirium among patients.

Most of the ICU patients’ areas of the Palestinian hospitals, which are below the standard area, are not provided the required daylight and mainly depend on artificial lights. Moreover, beds’ layout of the ICUs of all studied hospitals is arranged in a way that patients face the interior, even in newly designed hospitals, which makes access to view difficult for patients.

This study identifies the conditions of the ICU single room, two-bed-room and a patient area within an ICU ward that can enhance the average daylight factor and reduce the heating and cooling loads, while preserving the patient’s ability to access the outside view. The resulting optimum values of window orientation, window lintel level height, reflectance value and the used shading devices’ depth can be followed when designing an ICU in Palestine. On one hand, this would enhance the healing environment for patients, hence reduce the incidence of delirium and other health consequences resulted from the lack of daylight and access to view and improve the productivity of health providers and reduce medical errors on the other hand.

Optimization results show a significant relationship between the studied parameters and the average daylight factor as well as the energy consumption for heating and cooling, while light reflectance value has no significant impact on the heating and cooling loads. The optimal daylight factor as well as the minimal energy consumption were recorded at the south orientation for the three cases. The optimum values of window lintel level height, window to wall ratio, light reflectance value and shading device depth that related to each orientation for the ICU single room, the two-bed-room and the patient area within an ICU ward are in Table 7.1, 7.2 and 7.3 respectively.

Table 7.1: The optimum values of window lintel level height, window to wall ratio, light reflectance value and shading device depth that related to each orientation for an ICU single/isolated room.

Window Orientation	Window lintel level height (m)	Window to wall ratio (%)	Shading device depth	
			Horizontal (% of window height)	Vertical (% of window width)
North	2,5	30%	---	---
North-East	2,5	30%	---	20
East	2,5	30%	---	---
South-East	2,5	30%	20	20
South	2,25	30%	30	---
South-West	2,5	30%	10	50
West	2,5	30%	---	---
North-West	2,5	30%	---	60

Table 7.2: The optimum values of window lintel level height, window to wall ratio, light reflectance value and shading device depth that related to each orientation for an ICU two-bed room.

Window Orientation	Window lintel level height (m)	Window to wall ratio (%)	Shading device depth	
			Horizontal (% of window height)	Vertical (% of window width)
North	2,5	50%	---	---
North-East	2,5	50%	---	30
East	2,5	50%	---	---
South-East	2,75	50%	10	30
South	2,25	50%	20	---
South-West	2,5	40%	---	10
West	2,5	40%	---	---
North-West	2,5	50%	---	60

Table 7.3: The optimum values of window lintel level height, window to wall ratio, light reflectance value and shading device depth that related to each orientation a patient area within an ICU ward.

Window Orientation	Window lintel level height (m)	Window to wall ratio (%)	Shading device depth	
			Horizontal (% of window height)	Vertical (% of window width)
North	2,5	30%	---	---
North-East	2,5	30%	---	20
East	2,5	30%	---	---
South-East	2, 5	30%	10	10
South	2,25	30%	20	---
South-West	2,5	30%	---	30
West	2,25	30%	---	---
North-West	2,5	30%	---	40

The proposed shading devices have no significant impact on the energy consumption of east and west orientations for all cases, while other types of shading may negatively affect patient access to view. Therefore, treated glass such as reflective glass, glass treated with nanotechnology, tinted glass and ultraviolet filtering technology is recommended in these orientations. Furthermore, if the ICU is located on low-level floor, vegetative Shading is recommended as well.

In addition to the use of the appropriate values of the studied parameters, some strategies can be used to further enhance daylighting without negatively affecting heating and cooling loads. For instance, it was found that using a reflective plane at the window sill level would increase daylighting without affecting energy consumption, and window to wall ratio can be raised when using effective shading devices to maintain a balance between the daylight factor and the energy consumption. Moreover, a high light reflectance value can be achieved through the use of white paint instead of light green in the ICU room, this would raise the daylight factor and enhance light uniformity.

The previously mentioned optimum values of the parameters affecting daylight and access to view can be used to modify the current ICUs, in addition, to modify patients' areas to comply with the standard dimensions that the study is based on. This modification can enhance daylight and achieve access to view for most patients. However, it was found that the shallow plan designs are better than the deep plan designs in terms of daylight and access to view provision. Furthermore, the modification of the shallow plan ICUs resulted in more patients that have adequate daylight and access to view than the deep plan ICUs, which was found to be more challenging to be modified. Therefore, the ICUs of Alahli Hospital, Istishari Arab Hospital and An-Najah National University Hospital have a high potential for modification, while Alia Governmental hospital and Palestine Medical Complex have not. As shown in Figure 7.1. Table 7.4 shows the main findings of each phase of the research.

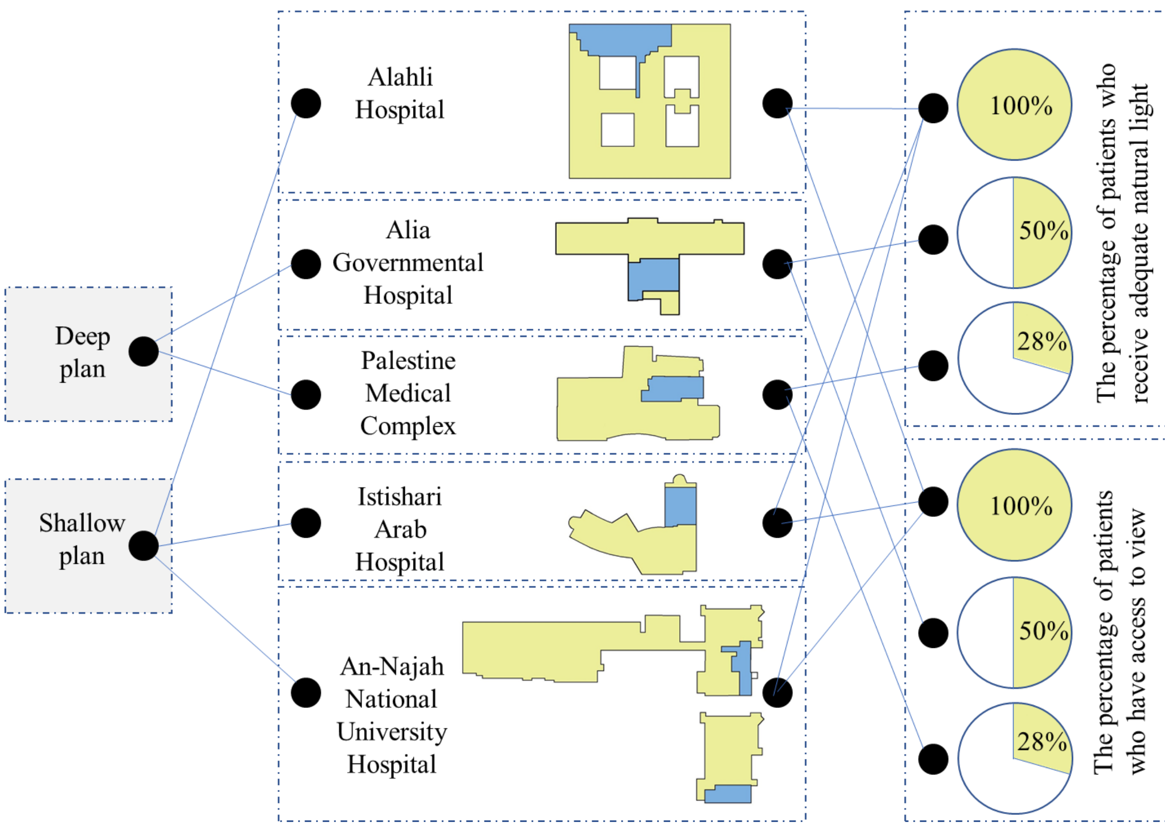


Figure 7.1: The percentage of patients who receive adequate daylight and have access to view in the ICUs of the studied hospitals after modification.

Table 7.3: The main findings of the research

Research phase	The main findings
1 EVALUATION of the Palestinian hospital in terms of daylight and access to view	- The designs of the ICUs of the Palestinian hospitals do not deliver adequate daylight and access to view for patients. - None of the ICU patients' areas of Alahli Hospital, Alia Governmental Hospital, Palestine Medical Complex and An-Najah National University Hospital have an average daylight factor of more than 3%. While 40% of ICU patients areas in Istishari Arab Hospital have an average daylight factor within the standards. - Beds layout in the studied ICUs does not support patients' visual contact with outside views. - The patient areas of the Palestinian hospitals are below the standard area. - There is a considerable incidence of delirium among ICU patients in Palestine.
2 OPTIMIZATION of the parameters that affects daylight in ICU patient areas	- ICU beds should be parallel to the external walls beside windows to achieve patients' access to view. - South orientation is the optimum for ICU windows in terms of achieving the optimal daylight and the minimal heating and cooling loads. - The optimum values of the window lintel level height of the studied models range between 2.25m and 2.75m. - The optimum values of the window to wall ratio of the studied models range between 30% to 50%. - The types and depths of the appropriate shading devices differ according to the case and its orientation. - Side fins are not an effective solution to the eastern and western windows. - Using white paint would enhance daylighting and maintain a good uniformity. - Using a reflective plane at the window sill level would raise the average daylight factor without affecting the heating and cooling loads.
3 ENHANCEMEN of the studied ICUs	- The optimization results can be used in the current ICUs. However, this requires a modification of the dimensions of patients' areas. - Shallow plan ICUs have a high potential for enhancement using the optimization results. This was applied to Alahli Hospital, Istishari Arab Hospital and An-Najah National University Hospital. However, deep plan ICUs has less enhancement potential. And areas that do not receive daylight and have no access to view are recommended to be occupied by unconscious patients.

7.1. Research Obstacles

The workflow of this research was affected by many obstacles as the following:

1. The lack of previous studies related to the design of ICU in light of the provision of appropriate daylight and natural views in Palestine that can be built upon or compared to.

2. The absence of database of delirious patients in the Palestinian hospitals and the lack of studies on the incidence of delirium in Palestine.

3. The current general conditions due to the spread of Coronavirus (COVID-19), which maximized the hospital visits limitations, and made it difficult to study some patient areas. This resulted in making multiple visits to find unoccupied areas for study.

4. The lack of cooperation of some hospitals and some departments in the Palestinian Ministry of Health in terms of providing the necessary information, especially with regards to architectural plans and photography inside the ICU.

5. The delay in obtaining permission to take daylight measurements inside the intensive care units, which made the measurements' dates different. It became necessary to wait for the days when the sky becomes overcast to take measurements and to take them in the early morning to avoid direct sunlight in order to maintain the validity of the measurements.

7.2. Recommendations:

1. In addition to the current and future ICU designs, the results of this study can be followed in the other hospital departments in Palestine, due to the similarity of daylight requirement. However, the study recommends further research to test the application of results in hospital wards that depend on natural ventilation.

2. Further research is also needed to precisely study the impact of applying results on the occurrence of discomfort and disability glare, particularly, window orientation, window to wall ratio and shading device's depth. Moreover, the study recommends for future studies to optimize the glass type, window position on the wall, window height and other types of shading devices in terms of daylight provision and patient access to view.

3. The study recommends for further research to investigate the effect of using deep shading device on the architectural form of building. Moreover, further research is needed to study the effect of high window to wall ratio on patients privacy.

4. The effect of orientation change on the average daylight factor should be investigated deeply and more studies should target the validity of simulation programs.

5. A database and comprehensive documentation should be established in the Palestinian hospitals. This should enhance the quality of treatment on one hand, and help in research purposes on the other.

6. The accumulative and sequent optimization steps used in this study provide faster results, when compared to cross analysis that tests all possible combinations. However, the later gives more accurate results. The same studied parameters are recommended to be tested using cross analysis, which may give different results.

7. The study recommends future research on the incidence of delirium among patients in Palestine and its relationship to the ICU design and the indoor environment quality.

8. Finally, the study emphasizes the importance of conducting this type of research, that depends on the optimization method, to improve the indoor environment quality in various types of building. Due to its great impact on human physical, mental and psychological health.

REFERENCES

1. English References

1) Abdin, A. R., Bakery, A. R. E. & Mohamed, M. A., 2018. The role of nanotechnology in improving the efficiency of energy use with a special reference to glass treated with nanotechnology in office buildings. *Ain Shams Engineering Journal,* December , 9(4), pp. 2671-2682.

2) Ahli-Hospital, 2020. *http://www.ahli.org.* [Online].

3) AIA, American Institute of Architects. & SBSE, Society of Building Science Educators, 2012. *Carbon Neutral Design Strategies: REDUCE LOADS / DEMAND FIRST - Shading (Heat Avoidance).* [Online]
Available at: https://www.tboake.com/carbon-aia/strategies1b.html

4) altensis, 2015. *https://www.altensis.com/.* [Online]
Available at: https://www.altensis.com/en/services/designbuilder-software/

5) Alzubaidi, S. et al., 2013. Survey of Hospitals Lighting: Daylight and Staff Prefernces. *International Journal of energy Engineering,* 3(6), pp. 287-293.

6) Amrein, K. et al., 2020. Vitamin D deficiency 2.0: An update on the current status worldwide. *European Journal of Clinical Nutrition,* pp. 1-16.

7) Anderson, D. C. & Halpern, N. A., 2016. Contemporary ICU Design. In: *Principles of Adult Surgical Critical Care.* s.l.:Springer, Cham, pp. 539-549.

8) Anderson, D., Jacoby, S. & Scruth, E., 2020. The Intersection of Architecture/Medicine/Quality and the Clinical Nurse Specialist: Designing for the Prevention of Delirium. *Clinical Nurse Specialist,* 37(1), pp. 5-7.

9) . *2030 palette.* [Online]
Available at: http://2030palette.org/
[Accessed 7 June 2020].

10) Aripin, S., 2006. *Healing architecture: a study on the physical aspects of healing environment in hospital design.* pp. 22-25.

11) Aripin, S., 2007. *'"Healing architecture: Daylight in hospital design.* Malaysia.

12) Asdrubali, F. & Desideri, U., 2019. Chapter 8 - Building Automation for Energy Efficiency: A Life Cycle Approach. In: *Handbook of Energy Efficiency in Buildings*, pp. 597-673.

13) Bellia, L., Cesarano, A., Iuliano, G. F. & Spada, G., 2008. Daylight glare: a review of discomfort indexes. *Visual quality and energy efficiency in indoor lighting: today for tomorrow.*

14) Beute, F. & de Kort, Y., 2018. The natural context of wellbeing: Ecological momentary assessment of the influence of nature and daylight on affect and stress for individuals with depression levels varying from none to clinical. *Health & place,* Volume 49, pp. 7-18.

15) Bion, J. & Dennis, A., 2016. ICU admission and discharge criteria. In: *Oxford Textbook of Critical Care (2 ed.).*Oxford University Press.

16) Boubekri, M., 2007. Daylight, architecture and people's health. *Environmental Health Risk,* Volume 31, pp. 1743-3525.

17) Boyce, P., Hunter, C. & Howlett, O., 2003. The Benefits of Daylight through Windows. *Sponsored by: Capturing the Daylight Dividend Program.*

18) Brambilla, A., Rebecchi, A. & Capolongo, S., 2019. Evidence Based Hospital Design. A literature review of. *Ann Ig,* Volume 31, pp. 165-180.

19) BREEAM, 2011. *Health and Wellbeing - Hea 01 Visual comfort.* [Online].

20) Brotas, L. & Wilson, M., 2008. The average total daylight factor. *Light & Engineering,* 16(2), pp. 52-57.

21) Butt, M. N. & Khan, M. F., 2018. Intensive Care Unit design; from advance to basic. *Pain & Intensive Care,* pp. S17-S20.

22) Causone , F., Rosa, F. D. & Pagliano , L., 2015. A review of indices for assessing visual comfort with a view to their use in optimization processes to support building integrated design. *Renewable and Sustainable Energy Reviews,* July, Volume 47, pp. 1016-1033.

23) Cesari, S., Valdiserri, P., Coccagna, M. & Mazzacane, S., 2018. Energy savings in hospital patient rooms: the role of windows size and glazing properties. *Energy Procedia,* Volume 148, pp. 1151-1158.

24) Chavoshani, A., Shams, A., Hassanzadeh, A. & Hashemi, M., 2017. Patients satisfactory from outdoor and indoor environments of a training hospital. *Journal of Advances in Environmental Health Research,* 5(3), pp. 183-191.

25) Choi, J. H., 2007. Study of the relationship between indoor daylight environments and patient average length of stay (ALOS) in healthcare facilities (Doctoral dissertation, Texas A&M University).

26) Chong, M. S. et al., 2013. Bright light therapy as part of a multicomponent management program improves sleep and functional outcomes in delirious older hospitalized adults. *Clinical Interventions in Aging,* 22 May.Volume 8.

27) Christoforos, C., 2012. Recommendations and standards for building and testing an Intensive Care Unit (ICU) electrical installation. *Department of Medicine (MDE).*

28) Coomber, S. et al., 2002. Stress in UK intensive care unit doctors. *British Journal of Anaesthesia,* December, 89(6), pp. 873-881.

29) El Sherif, S. K., 2012. The impact of overhangs and side-fins on building thermal comfort, visual comfort and energy consumption in the tropics (Doctoral dissertation, The British University in Dubai (BUiD)).

30) Engineering ToolBox, 2012. *Materials - Light Reflecting Factors.* [Online]
Available at: https://www.engineeringtoolbox.com/light-material-reflecting-factor-d_1842.html
[Accessed 27 June 2020].

31) Englezou, M. & Michael, A., 2020. Assessment of daylight performance and the impact of shading devices for typical in-patient rooms in healthcare facilities in Cyprus. *Procedia Manufacturing,* Volume 44, pp. 277-285.

32) Faiola, A. & Newlon, C., 2011. Advancing Critical Care in the ICU: A Human-Centered Biomedical Data Visualization Systems. *Ergonomics and Health Aspects of Work with Computers,* pp. 119-128.

33) FICANZCA, 2011. *Minimum Standards For Intensive Care Units.* [Online].

34) Figueiro, M., 2017. Light, sleep and circadian rhythms in older adults with Alzheimer's disease and related dementias. *Neurodegenerative disease management,* 7(2), pp. 119-145.

35) Fisekis, K., Davies, M., Kolokotroni, M. & Langford, P., 2003. Prediction of discomfort glare from windows. *Lighting Research & Technology,* 35(4), p. 360–371.

36) Frumkin, H. et al., 2017. Nature contact and human health. *A research agenda. Environmental health perspectives,* 125(7).

37) Fuchs, S. et al., 2020. Delirium in elderly patients: Prospective prevalence across hospital services. *General Hospital Psychiatry,* Volume 67, pp. 19-25.

38) Gorantla, K. K., Shaik, S. & Setty, A. B., 2018. Day lighting and thermal analysis using various double reflective window glasses for green energy buildings. *International Journal of Heat and Technology,* September, 36(3), pp. 1121-1129.

39) Green Building Index .2020 ‹*www.greenbuildingindex.org.* [Online].

40) Available at :https://www.greenbuildingindex.org/resources/20110329/

41) Guenther, R. & Hall, A. G., 2007. Healthy Buildings: Impact on Nurses and Nursing Practice. *The Online Journal of Issues in Nursing,* 31 May .12(2).

42) Hamilton, D., 2020. Design for critical care. In: *Design for Health.* Academic Press, pp. 129-145.

43) Hanforda, N. & Figueiro, M., 2012. Light Therapy and Alzheimer's Disease and Related Dementia: Past, Present, and Future. *Journal of Alzheimer's Disease,* Volume 33, p. 913–922.

44) Hanieh, A. M. A., 2019. *Automatic Orientation Of Solar Photovoltaic Panels To Increase Efficiency.* [Online]
Available at: http://hdl.handle.net/20.500.11889/4125

45) Hashemighouchani, H. et al., 2020. The Impact of Environmental Risk Factors on Delirium and Benefits of Noise and Light Modifications: A Scoping Review. *medRxiv.*

46) Haspel, J. et al., 2020. Perfect timing: circadian rhythms, sleep, and immunity—an NIH workshop summary. *JCI insight,* 5(1).

47) IAH, 2017. *http://www.iah.ps/articles/article/165.* [Online]
[Accessed 27 August 2020].

48) Iversen ،A. et al., 2013. Daylight calculations in practice: An investigation of the ability of nine daylight simulation programs to calculate the daylight factor in five typical rooms.

49) ICS, Intensive Care Society, 1997. Guidelines on Admission to and Discharge from Intensive Care and High Dependency Units. *UK Department of Health,* March .

50) Iyendo, O. & Alibaba, H. Z., 2014. Enhancing the Hospital Healing Environment through Art and Day-Lighting for User's Therapeutic Process. Vol 3.; 2014.. *International journal of arts and commerce,* 3(9), pp. 101-119.

51) Iyendo, T. O., 2004. Enhancing the Hospital Healing Environment through Art and Day-lighting for User's Therapeutic Process. *International Journal of Arts and Commerce,* December.3(9).

52) Jakubiec, J. & Reinhart, C., 2012. The 'adaptive zone' – A concept for assessing discomfort glare throughout daylit spaces. *Lighting Research & Technology,* Volume 44, p. 149–170.

53) Jamshidi, S., Parker, J. & Hashemi, S., 2019. The effects of environmental factors on the patient outcomes in hospital environments: A review of literature. *Frontiers of Architectural Research.*

54) Jiang, C., Xing, J., Ling, J. & Qin, X., 2012. Energy consumption and carbon emissions of hospitals in Tianjin. *Frontiers in Energy,* 6(4), pp. 427-435.

55) Jongerden, I. et al., 2013. Intensive care medicine. *Effect of intensive care environment on family and patient satisfaction: a before–after study,* 39(9), pp. 1626-1634.

56) Jorge, J., Puigdomenech, J. & Cusido, J., 1993. A practical tool for sizing optimal shading devices. *Building and Environment,* 1 January, 28(1), pp. 69-72.

57) Kaminska, A., 2020. Impact of Building Orientation on Daylight Availability and Energy Savings Potential in an Academic Classroom. *Energies,* 13(18), p. 4916.

58) Kirimtat, A., Koyunbaba, B., Chatzikonstantinou, I. & Sariyildiz, S., 2016. Review of simulation modeling for shading devices in buildings. *Renewable and Sustainable Energy Reviews,* 1 January, Volume 53, pp. 23-49.

59) Knoop, M. et al., 2020. Daylight: What makes the difference?. *Lighting Research & Technology,* 52(3), pp. 423-442.

60) Kočovská, E., Gaughran, F., Krivoy, A. & Meier, U., 2017. Vitamin-D deficiency as a potential environmental risk factor in multiple sclerosis, schizophrenia, and autism. *Frontiers in psychiatry,* Volume 8, p. 47.

61) Konkani, A., Oakley, B. & Penprase, B., 2014. Reducing Hospital ICU Noise: A Behavior-Based Approach. *Journal of Healthcare Engineering,* 5(2), pp. 229-246.

62) Kubba, S., 2012. Indoor Environmental Quality. In: *Handbook of Green Building Design and Construction*. pp. 313-360.

63) Lawson, B., 2010. Healing architecture. *Arts & Health,* 2(2), p. 95 — 108.

64) Leccese, F., Montagnani, C., Rocca, S. I. M. & Salvadori, G., 2016. Quality of Lighting in Hospital Environments: A Wide Survey Through in Situ Measurements. *Journal of Light & Visual Environment,* June .Volume 40 .

65) Lechner, N., 2014. *Heating, cooling, lighting: Sustainable design methods for architects.* John wiley & sons.

66) Lee, E. & Kim, J., 2016. Cost-benefit analysis of a delirium prevention strategy in the intensive care unit. *Nursing in Critical Care,* November , 21(6), pp. 367-373.

67) Maleki, A. & Dehghan, N., 2020. Optimization of energy consumption and daylight performance in residential building regarding windows design in hot and dry climate of Isfahan. *Science and Technology for the Built Environment,* pp. 1-16.

68) Mangkuto, R. A., Rohmah, M. & Asri, A. D., 2016. Design optimization for window size, orientation, and wall reflectance with regard to various daylight metrics and lighting energy demand: A case study of buildings in the tropics. *Applied energy,* Volume 164, pp. 211-219.

69) Manzan, M. & Pinto, F., 2009. *GENETIC OPTIMIZATION OF EXTERNAL SHADING DEVICES.* Glasgow.

70) MaterialsCouncil, 2012. *Whiter than white,* London.

71) Milbrandt, E. B. et al., 2004 . Costs associated with delirium in mechanically ventilated patients. *Critical Care Medicine,* 32(4), pp. 955-962.

72) Mohelnikova, J. & Hirs, J., 2016. Effect of externally and internally reflective components on interior daylighting. *Journal of Building Engineering,* Volume 7, pp. 31-37.

73) Mourshed, M. & Zhao, Y., 2012. Healthcare providers' perception of design factors related to physical environments in hospitals. *Journal of Environmental Psychology,* 32(4), pp. .362-370.

74) Münch, M. et al., 2020. The role of daylight for humans: Gaps in current knowledge. *Clocks & Sleep,* 2(1), pp. 61-85.

75) NCBI, The National Center for Biotechnology Information. *Tertiary Care Centers - MeSH - NCBI.* [Online]
Available at: www.ncbi.nlm.nih.gov
[Accessed 3 November 2020].

76) Negro, D., Johannes, A. H. & Cammaert, L. M. G. I., 2014. *Carpet with a High Light Reflectance Value and Method of Producing such Carpet.* U.S., Patent No. 14/355,686.

77) Neufert, E. & Neufert, P., 2012. *Architects' data.* John Wiley & Sons.

78) Nussbaumer-Streit, B. et al., 2019. Light therapy for preventing seasonal affective disorder. *Cochrane Database of Systematic Reviews,* Volume 3.

79) Olbina, S. & Beliveau, Y., 2009. Developing a transparent shading device as a daylighting system. *Building Research & Information,* 37(2), pp. 148-163.

80) Osmancevic, A. et al., 2009. Effect of climate therapy at Gran Canaria on vitamin D production, blood glucose and lipids in patients with psoriasis. *European Academy of Dermatology and Venereology,* Volume 23, p. 1133–1140.

81) Ouimet, S. et al., 2007. Subsyndromal delirium in the ICU: evidence for a disease spectrum. *Intensive Care Med,* Volume 33, p. 1007–1013.

82) Pai, M. Y. & Siddhartha, 2015. Effect of Building Orientation and Window Glazing on the Energy Consumption of HVAC System of an Office Building for Different Climate Zones. *International Journal of Engineering Research & Technology (IJERT),* September.4(09).

83) Panaz, 2020. [Online]
Available at: http://www.panaz.com/en/collections/products/search/colours/green/end-uses/healthcare-upholstery_sheer-curtains/
[Accessed 8 July 2020].

84) PHIC, Palestine Health Information Center, 2019. *Health Anual Report- Paletine 2018,* Ministry of Health-State of Palestine.

85) Raanaas, R. K., Patil, G. G. & Hartig, T., 2012. Health benefits of a view of nature through the window: a quasiexperimental study of patients in a experimental study of patients in a residential rehabilitation center. *Clinical Rehabilitation,* 26(1), p. 21–32.

86) Rafeeq, D. & Mustafa, F., 2020. Evidence-based design: The role of inpatient typology in creating healing environment, hospitals in Erbil city as a case study. *Ain Shams Engineering Journal.*

87) Rompaey, B. V. et al., 2009. Risk factors for delirium in intensive care patients: a prospective cohort study. *Critical Care*, May.Volume 13.

88) Rubert, R., Long, L. D. & Hutchinson, M. L., 2007. Creating a Healing Environment in the ICU. *Critical Care Nursing: Synergy For Optimal Outcomes,* pp. 27-39.

89) Saradj, F. M., Ahadi, A. A., Maleki, N. & Masumi, H., 2014. Making balance between optimum daylight and thermal comfort in hothumid climates, Case study: Rashidy historic mansion in Bushehr city, Iran. *International Journal of Architectural Engineering & Urban Planning,* December .24(2).

90) SCCM, Society Of Critical Care Medicine, 1995. Guidelines for Intensive Care Unit Design. *Critical Care Medicine*, March, 23(3), pp. 582-588.

91) Shamout, S., 2016. *Green Buildings and Energy Efficiency,* New zealand: the University of Auckland.

92) Shedler, J., 2020. Where is the evidence for "evidence-based" therapy?. In: *Outcome Research and the Future of Psychoanalysis: Clinicians and Researchers in Dialogue.*

93) Shen, H. & Tzempelikos, A., 2014. *A global method for efficient synchronized shading control using the "effective daylight" concept*.

94) Shepley, M. M. et al., 2012. The Impact of Daylight and Views on ICU Patients and Staff. *Health Environments Research & Design (HERD),* January, 5(2), pp. 46-60.

95) Sherif, A. et al., 2015. The Impact of Hospital Intensive Care Unit Window Design on Daylighting and Energy Performance in Desert Climate. *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering,* 9(7).

96) Sherif, A. et al., 2016. Shaping the slats of hospital patient room window blinds for daylighting and external view under desert clear skies. *Solar Energy,* Volume 133, pp. 1-13.

97) Shikder, S. H., Mourshed, M. & Price, . D. A., 2010. *Optimization of a daylight-window: hospital patient room as a test case*.

98) Simons, K., 2018. The ICU environment. Impact of light and noise exposure. *Redboud repository.*

99) Skrobik, Y., 2009. Broadening our perspectives on ICU delirium risk factors. *Critical Care,* 1 July.13(160).

100) Stidsen, L. M., Kirkegaard, P. H. & Fisker, A. M., 2009. *Lighting quality in hospital wards - State of the art*, Design parameters for a pleasurable light atmosphere. Aalborg: Department of Civil Engineering, Aalborg University.

101) Tao, Q., Jiang, F. L. Z. & Zheng, J., 2020. A model of heat gain calculation for buildings with shuttle louvers: Verification and a case study. *Journal of Building Engineering*, Volume 29, p. p.101101.

102) Teltsch, D. Y. et al., 2011. Infection Acquisition Following Intensive Care Unit Room Privatization. *JAMA Internal Medicine.*

103) Thompson, D. R. et al., 2012. Guidelines for intensive care unit design. *Critical Care Medicine*, 40(5).

104) Tuchinda, C., Srivannaboon, S. & Lim, H. W., 2006. Photoprotection by window glass, automobile glass, and sunglasses. *Journal of the American Academy of Dermatology*, 54(5), pp. 845-854.

105) Ulrich, R. et al., 2004. The Role of the Physical Environment in the Hospital of the 21 St Century: A Once-in-a-Lifetime Opportunity.

106) Ulrich, R. S., 1984. View through a window may influence recovery from surgery. *Science: New Series*, 224(4647), pp. 420-421.

107) Ulrich, R. S. et al., 2008. A Review of the Research Literature on Evidence-Based Healthcare Design (Part I). *Health Environments Research & Design*, 1(3).

108) Vahedian-Azimi, A., Bashar, F., Khan, A. & Miller, A., 2020. Natural versus artificial light exposure on delirium incidence in ARDS patients. *Annals of Intensive Care*, 10(1), pp. 1-3.

109) Vanhoutteghem, L., Skarning, G. C. J., Hviid, C. A. & Svendsen, S., 2015. Impact Of Façade Window Design On Energy, Daylighting And Thermal Comfort In Nearly Zero-Energy Houses. *Energy and Buildings*, Volume 102, pp. 149-156.

110) Vasilevskis, E. E. et al., 2018. The Cost of ICU Delirium and Coma in the Intensive Care Unit Patient. *Med Care*, October, 56(10), p. 890–897.

111) Villalba, A., Monteoliva, J. & Pattini, A., 2020. Development of a simplified light reflectance value assessment tool for indoor surface coverings. *Indoor and Built Environment.*

112) Vyveganathan, L. et al., 2019. Delirium in critically ill patients: incidence, risk factors and outcomes. *Critical Care & Shock*, 22(1).

113) Walker, W., Walton, J., DeVries, A. & Nelson, R., 2020. Circadian rhythm disruption and mental health. *Translational Psychiatry*, 10(1), pp. 1-13.

114) Wang, S. & Chen, M., 2020. The effects of sunlight exposure therapy on the improvement of depression and quality of life in post-stroke patients: A RCT study. *Heliyon,* 6(7), p. e04379.

115) Weinrebe, W., Johannsdottir, E., Karaman, M. & Füsgen, I., 2016. What does delirium cost? : An economic evaluation of hyperactive delirium. *Zeitschrift für Gerontologie und Geriatrie,* January , 49(1), p. 52–58.

116) White, R. D., 2003. Individual Rooms in the NICU — An Evolving Concept. *Journal of Perinatology volume,* Volume 23, p. S22–S24.

117) Yao, J., 2014. An investigation into the impact of movable solar shades on energy, indoor thermal and visual comfort improvements. *Building and Environment,* Volume 71, pp. 24-32.

118) Zijlstra, E., Hagedoorn, M., van der Schans, C. & Mobach, M., 2020. The Patient Journey in a Hospital Environment. *Companion Proceedings of EFMIC 2020*, p. 59.

119) Zimring, C., Joseph, A. & Choudhary, R., 2004. The Role of the Physical Environment in the Hospital of the 21st Century: A Once-in-a-Lifetime Opportunity. *Concord, CA: The Center for Health Design,* September.

a. 2. Arabic Reference

120) GSQD, (Government Services Quality Departmen) دائرة جودة الخدامات الحكومية, 2018. *تقرير متابعة التقييم الخاص في المستشفيات الحكومية ومديريات الصحة والرعاية الأولية في المحافظات الشمالية 2017-2018. فلسطين*

a. 3. Interviews

121) Abu-Arish, Z., 2020. *A nurse in the ICU of Al-Ahli hospital* [Interview] (3 February 2020).

122) Abu-Hanieh, H., 2020. *A nurce in the ICU of Al-Ahli hospital* [Interview] (3 February 2020).

123) Abu-Omar, W., 2020. *A sineor nurse in the medical ICU of An-Najah National University Hospital* [Interview] (9 september 2020).

124) Al-Bayaa, D. A.-A., 2020. *Head Doctor of the ICU of Al-Ahli hospital* [Interview] (3 February 2020).

125) Aljubeh, M., 2020. *The electrical engineer of Alahli hospital* [Interview] (3 Fecruary 2020).

126) Asafrah, A., 2020. *A nurse in the ICU of Alia Governmental Hospital* [Interview] (19 February 2020).

127) Atawneh, K., 2020. *An engineer in the engineering and construction department, Ministy of Health* [Interview] (23 February 2020).

128) Ghawadreh, A., 2020. *The electrical engineer of Palestine Medical Complex* [Interview] (29 July 2020).

129) Halaiqa, R., 2020. *Head nurse of the ICU in Istishari Arab Hospital* [Interview] (29 July 2020).

130) Mansur, N., 2020. *A nurse in the ICU of Istishari Arab Hospital* [Interview] (29 July 2020).

131) Qudaimat, D. M., 2020. *The head doctor of the ICU of Alia Governmental Hospital* [Interview] (27 February 2020).

132) Sarees, I., 2020. *A nurse in the surgical ICU of An-Najah National University Hospital* [Interview] (9 september 2020).

133) Silmi, S., 2020. *Head nurse of the ICU of Al-Ahli Hospital, Hebron* [Interview] (3 February 2020).

134) Sultan, S., 2020. *Civil engineer in the maintenance department of Alahli hospital* [Interview] (3 February 2020).

135) Tumeh, E., 2020. *Head nurse of the ICU of Palestine Medical Complex* [Interview] (29 July 2020).

APPENDICES

Appendix A: Measurement results of indoor and outdoor illuminance achieved by daylight

Table A.1, A.2, A.3, A,4 and A.5 show the measurement results of the indoor and outdoor illuminance in the studied ICU patients' areas when the artificial lights are turned off.

Table A.1: Measurement results of indoor and outdoor illuminance achieved by daylight in Alahli Hospital

Indoor illuminance (lux) — colour scale: Maximum value / Average value / Minimum value

Patient area number 1

157	165	149	40	50	27
100	105	154	66	65	40
109	143	165	91	68	50
118	182	170	110	110	80
125	205	146	150	123	75
144	241	207	195	133	67
183	277	329	241	235	57
202	430	390	390	438	48
140	179	445	602	540	44
77	75	77	157	120	40

Patient area number 2

7	15	9	5
9	14	14	9
23	22	11	12
25	34	34	17
21	39	38	18
22	30	29	14
22	21	20	10
10	11	12	7
5	4	7	3

Patient area number 3

1	1	1	1
2	7	4	1
2	7	7	2
0	6	10	1
0	6	8	1
0	0	0	0
0	0	0	0

Outdoor illuminance (lux): 10820

Measuements were taken under overcast sky conditions during the morning from 9A M to 10 AM in 8/4/2020.

Table A.2: Measurment results of indoor and outfoor illuminance achieved by daylight in Alia Governmental Hospital

Patient area number: 1 | 2

Indoor illuminance (lux) — color scale: Maximum value / Average value / Minimum value

Patient area 1				Patient area 2			
30	33	161	32	0	0	0	0
114	169	233	87	0	0	0	0
116	262	308	223	0	0	0	0
197	490	454	413	0	0	0	0
206	406	521	302	0	0	0	0
215	321	588	190	0	0	0	0
208	313	447	166	0	0	0	0
201	305	305	142	0	0	0	0
161	287	377	194				

Outdoor illuminance (lux): 10818 lux

Measuements were taken under overcast sky conditions during the morning from 10:30 AM to 11:30 AM in 8/4/2020.

Table A.3: Measurment results of indoor and outdoor illuminance achieved by daylight in Palestine Medical Complex

Patient area number: 1 | 2 | 3

Indoor illuminance (lux) — color scale: Maximum value / Average value / Minimum value

Patient area 1				Patient area 2				Patient area 3			
38	51	54	51	0	0	0	0	0	0	0	0
46	61	64	63	0	0	0	0	0	0	0	0
74	115	99	119	0	0	0	0	0	0	0	0
97	115	111	111	0	0	0	0	0	0	0	0
83	99	100	94	0	0	0	0	0	0	0	0
68	77	77	73	0	0	0	0	0	0	0	0
				0	0	0	0	0	0	0	0
				0	0	0	0	0	0	0	0

Outdoor illuminance (lux): 12100

Measuements were taken under overcast sky conditions during the morning from 9:00 AM to 10 AM in 1/9/2020.

Table A.4: Measurment results of indoor and outdoor illuminance achieved by daylight in Istishari Arab Hospital

Patient area number: 1

Indoor illuminance (lux) — colour scale: Maximum value / Average value / Minimum value

267	1861	1772	270	153
582	601	572	385	269
266	287	256	160	200
134	153	195	150	153
118	127	131	154	115
85	102	106	111	85

Patient area number: 2

2009	881	126	83	70	58
1230	2089	1190	190	119	67
1629	1000	744	157	133	87
1000	844	622	200	158	120
571	442	313	171	132	136
300	246	175	143	113	144
136	152	144	133	162	172

Outdoor illuminance (lux): 11870

Measuements were taken under overcast sky conditions during the morning from 8:00 AM to 8:30 AM in 2/9/2020.

Table A.5: Measurment results of indoor and outdoor illuminance achieved by daylight in An-Najah National University Hospital

Patient area number: 1

Indoor illuminance (lux) — colour scale: Maximum value / Average value / Minimum value

150	800	1500	700
155	663	1465	445
165	129	400	333
160	188	182	183
146	103	152	152
103	76	109	128

Patient area number: 2

25	97	274	810	1000	810	274
13	240	462	382	291	382	462
160	209	277	301	295	301	277
141	163	200	210	193	210	200
124	143	165	172	166	172	165
106	122	130	133	139	133	130

Patient area number: 3

7	9	4	6	6
6	12	7	9	10
8	13	11	12	15
7	15	15	7	11
3	23	18	13	9

Outdoor illuminance (lux): 13880

Measuements were taken under overcast sky conditions during the morning from 8:00 AM to 8:30 AM in 9/9/2020.

Appendix B: Interviews questions

The following are the questions of the interviews conducted with the ICU medical staff of the studied hospitals:

1. Is there a noticeable effect of natural lighting on patient and medical staff satisfaction?
2. Are there preferences for ICU patients regarding the bed location, close to a window or not?
3. Is glare observed in the space, and are there any complaints from patients about it?
4. Do patients ask significantly about time?
5. Do patients frequently ask to change their beds location?
6. Are there common health problems among the ICU patients related to lack of natural lighting, such as sleep problems or depression?
7. Do patients significantly develop delirium?
8. What is the treatment plan followed for delirious patients? Does the indoor environment have a role in it?
9. How can the ICU environment be improved? What is the role of the ICU design in the improvement?