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Analysis of Daylight Performance of a Courtyard House: A Case Study of Prototype House in Riyadh City, Saudi Arabia

Dr. Amjed A. Maghrabi
Head Of Researches & Consultations
Assistant Professor, Department of Islamic Architecture
College of Engineering & Islamic Architecture,
Um Al-Qura University

تحليل أداء الضوء الطبيعي للمسكن ذو الفناء
دراسة حالة نموذج لمسكن تكرارى – مدينة الرياض – المملكة العربية السعودية

دكتور أمجد بن عبد الرحمن مغربي
رئيس قسم الاستشارات والبحوث
أستاذ العمارة المساعد – قسم العمارة الاسلامية
كلية الهندسة والعمارة الاسلامية – جامعة أم القرى

المستخلص العربى:
يعد المسكن ذو الفناء الداخلى من الحلول التصميمية واسعة الانتشار فى المناطق المناخية الحارة الجافة. من الناحية البينية فان هذا الحل يستخدم لتحسين الاداء الحرارى إضافة إلى فائدته فى توفير الاضاءة الطبيعية المناسبة خاصة للفراغات التي ليس لها مصادر إضاءة على الحوائط الخارجية. فهناك العديد من المساكن ذات الفناء التى صممت دون النظر إلى توفير الاضاءة الكافية. وتهتم هذه الدراسة باداء المسكن ذو الفناء الضونى خاصة النماذج التكرارى واسعة التطبيق بمدينة الرياض – المملكة العربية السعودية.
وتحتوى الدراسة على تعريف بالظروف الجغرافية والمعمارية لمدينة الرياض ومن ثم تعرض للنموذج الدارسى واسباب إختياره و مكوناته المعمارية. ومن ثم تنتقل إلى طريقة حساب الزوايا الشمسية لمدينة الرياض وكذلك اسلوب التصوير الضونى لعدد من فراغات المسكن و كيفية اختيار توقيت التصوير. كما يتضمن البحث تحليل متعمق لنتائج التصوير ويخلص إلى عدد من التوصيات لتحسين الاداء الضونى لفراغات هذا النموذج التكرارى.

Abstract:
The Introverted design concept is widely applied in hot dry climatic zones. From the environmental point of view, the main purpose of having a courtyard house is to control the thermal performance as well as to provide daylight for spaces that have not an opening on the external walls. Many courtyard houses are designed with less consideration for daylight performance. This study focuses on the investigation of the daylight performance in a typical- prototype- courtyard house in Riyadh, Saudi Arabia.
The study contains an overview of solar characteristics of Riyadh city. Then it focuses on the selected design, collection of Riyadh city solar and end up with a daily and annually picturing of a three dimensional model in order to record the existing daylight performance of the building. The study concludes with a general observations and recommendations of the daylight performance for the selected design.

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1. Introduction:

The Introverted design concept is widely applied in hot dry climatic zones (1,2,3). However, many courtyard houses are designed with fewer considerations for daylight performance. This study focuses on the investigation of the daylight performance in a typical- prototype- courtyard house in Riyadh, Saudi Arabia.

An overview of climate of Riyadh, solar data of the city and criteria considered for the selected residential house is discussed first. The measuring technique and the observation setup are also discussed in detail. The study concludes with general observations and recommendations of the daylight performance for the selected design.

This investigation evolves daylight performance to be a design tool at the early design stages. Moreover, the study show how an intensive analysis of daylight performance of a courtyard house would enhance daylight performance within the building enclosure. The results and conclusions achieved from the study can support other daylight investigations. It also assists designers - in hot dry climate- to achieve an optimum results of daylight performance by changing the four variables i.e.; fenestration, structure orientation and shading devices location through different design stages.

2. Location & Solar Data of Riyadh City:

Riyadh is one of the middle region cities of Saudi Arabia. It is located at a latitude of 24 42"N, 46 44'E (4). Desert that covers most parts of the Riyadh is mainly hot dry arid and semi-arid desert. Annual perception of Riyadh City reaches 1.6 with peaks in January, March, November and December (3). Figure (1) illustrates the sun path diagram of Riyadh city.

Riyadh has generally two seasons (summer, winter). With low humidity, temperature rates from 75-117 F between day and night during summer, and 34-84 F during winter (3,4). Clear sky - with no clouds- most of the year, with an inconsiderable annual rainfall. As a result, direct solar radiation is intense and is augmented by radiation reflected from the barren, light-colored terrain.

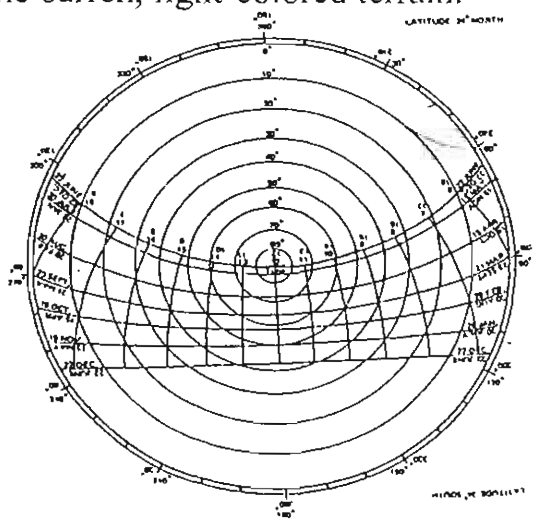

Figure 1: Solar chart of the sun path diagram of Riyadh city" latitude 24 42'N, 46 44'E"

3. The Case Study:

The criteria for selecting the case study was that, the house design and form should represent a typical prototype houses in Riyadh. The selected design has taken into consideration the codes and criteria applicable in Islamic Societies, such as gardening of areas and spaces with a special attention to having different levels of privacy ass shown if figures (2- 4). The selected design consists of one floor building with internal courtyard (5).

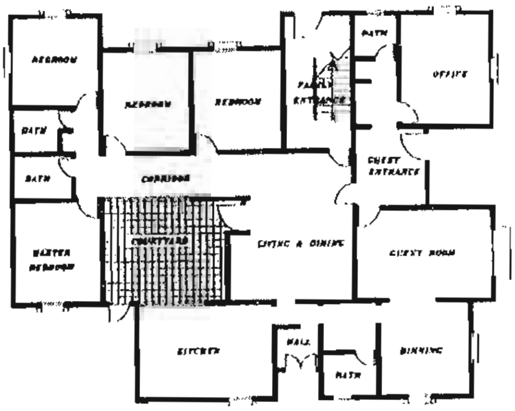

Figure 2: The Ground Floor Plan.

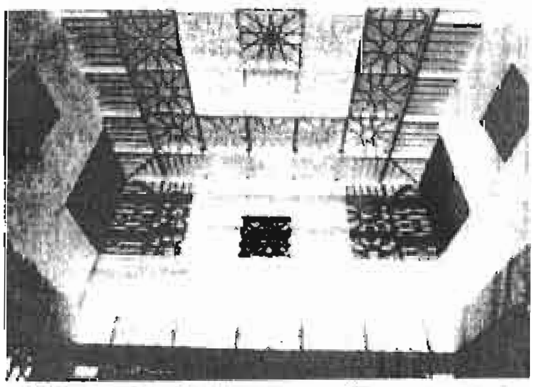

Figure 3: Picture to Courtyard Shading Device (Pergulla).

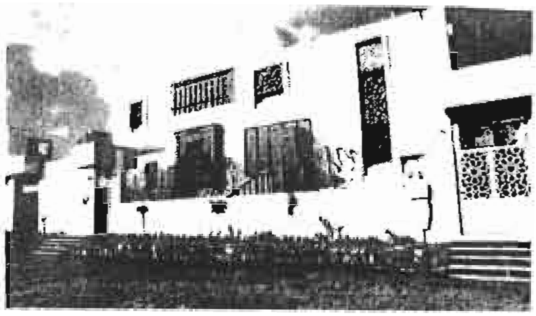

Figure 4: The Case Study from Outside.

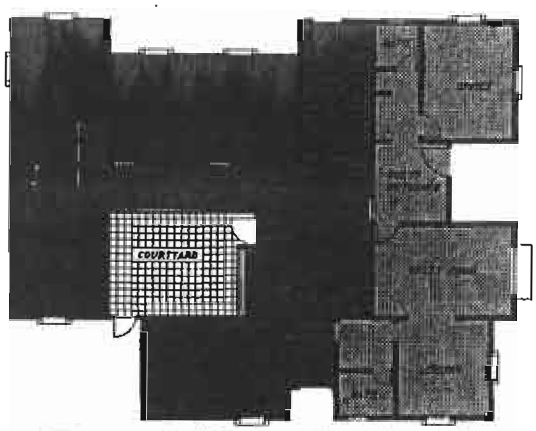

Figure 4: Floor plan showing different privacy levels.

3.1. Selected Spaces for Investigation:

Daylight performance will be examined for spaces that overlook the courtyard; kitchen, living space, corridor and master bedroom. The analysis of daylight performance of these spaces is initially based on the study of the daily penetration of direct light penetrating the courtyard. Only kitchen is observed with the daylight penetrating from courtyard as well as from the window on the southern wall. Figure 5 shows the selected spaces for study and the camera positions for observation.

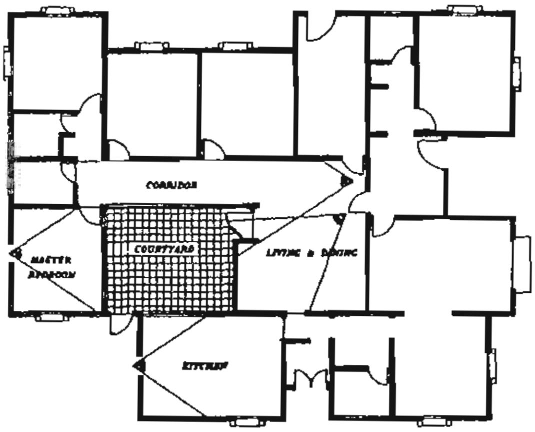

Figure 5: Selected Rooms for Daylight Investigation and Camera Positions.

4. Sun Path Simulation:

Sun latitude and azimuth angles of Riyadh are collected (4). There are different systems that sun angles can be observed. However, this paper will consider be based only on the so-called "sun path diagram" (6)(appendix I)

4.1. Daily and Monthly Sun Path Data of Riyadh:

Depending on the type of investigation and the level of observations accuracy, daily Sun path can be recorded three to all daytime hours. Monthly investigation of sun path can also be recorded three months to the whole year(2,5,6,7). The more hours and months sun path is investigated, the more accurate results is achieved.

This investigation is based on the record of seven hours a day : 7 am, 9 am, 10 am, 11 am, 12 PM, 2 PM, 4 PM, 6 PM, and seven months a year : June 22, May 15, Apr. 15, Mar. 21, Feb. 28, Jan. 28, Dec. 22. As shown in the sun path diagram, the selected hours and days represent the sun path for all day hours and whole months of the year (Appendix II). Figure 6 demonstrates the calculations of the sun positions within Riyadh area during January, February, March, April, May, June and December. Similar technique is found in the work of Tabb (8).

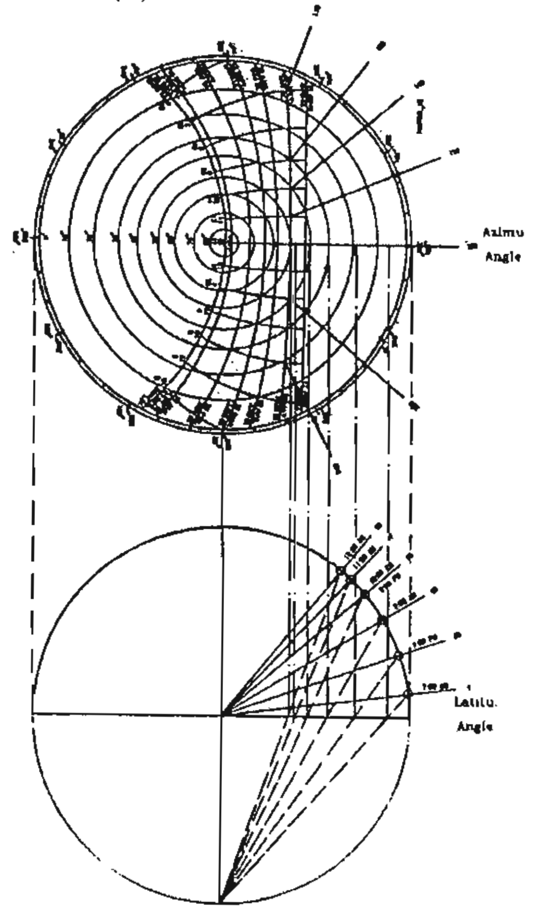

Figure 6: Example of Sun Positions Calculations for Riyadh

4.2. Picturing Technique and Observation Methodology

The investigation was conducted through simulating the sun path during the selected times and days and picturing the model. The impact of the natural light is explicit through the picturing of the four selected spaces and courtyard.

A three-dimensional mock-up for the design in hand with a scale of 1:20 was constructed for this purpose. The model was then examined under the clear-sky conditions in Riyadh. As discussed earlier, four different locations of cameras were carefully selected for the investigation (Figure 5).

The objective of the picturing is to show how different spaces are influenced by natural light and how sun radiation's penetrate the courtyard to each space. Further, pictures will be observed and analyzed to identify spaces that have optimum natural ventilation from those that need modifications (8).

The four selected spaces are pictured every hour to give the real simulation of Riyadh sun path. Appendix III demonstrates an example for the model pictures for the selected hours during one of the previously defined months.

5. Results and Analysis:

The results for every space of the four selected spaces are introduced in the following section:

5.1. Living Space:

Because of the window orientation, living space is not influence by sun light. Picturing of summer period resulted in an adequate lighting distribution for the living space. Although the living space window is facing west, the mentioned space is well lit at 9:00 AM, 10:00 AM and 11:00 AM. Picturing showed light was originated from reflection of the other courtyard surfaces. Most of direct light was penetrating at the time between 1:00 PM to 4:30 PM (Figure 7-8). No direct light was recorded in December (the coldest month of the year). The highest quantity of light is penetrating at 2:00 PM. Full analysis of the observation as well as daylight performance is shown in Appendix IV-a.

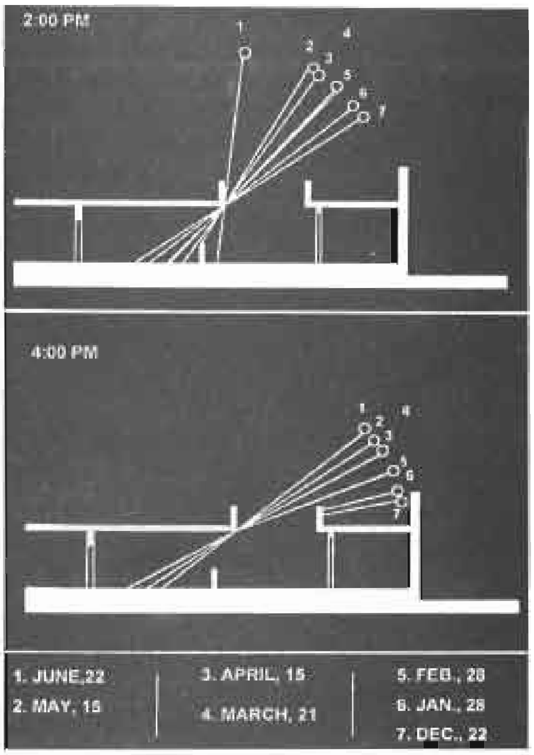

Figure 7: Sun Angles and Light Penetration through living space.

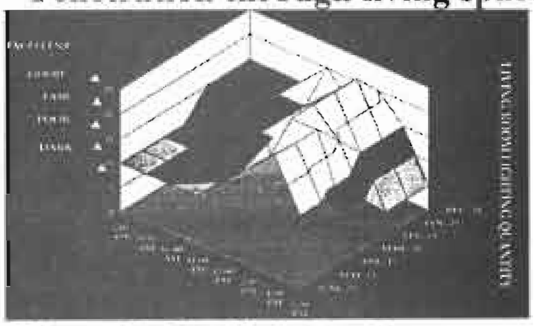

Figure 8: Daylight Performance for living Space.

5.2. Bedroom:

The opening that overlooking courtyard just allow sun penetration during 9:00 AM and 10:00 AM. On the other hand window on the southern direction permits direct sun light at noon in both January and December. The opening on the courtyard side is not designed to enhance daylight penetration during winter.

The sun path showed the best sequence of lighting hierarchy that is obviously required to accumulate summer and winter seasons.

The room was found mostly illuminated at the 10:00 AM's (Figure 9-10).

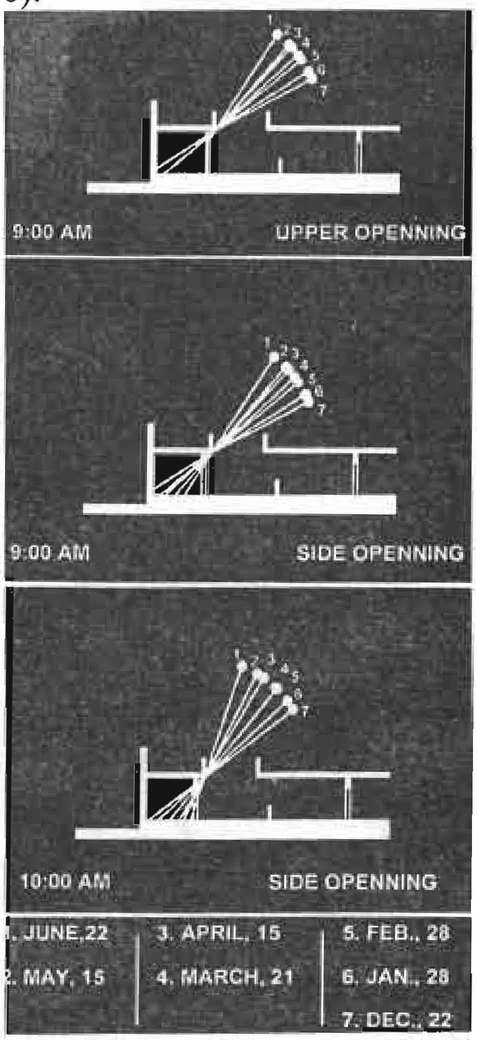

Figure 9: Sun Angles and Light Penetration Through Bedroom.

In march -one of the summer seasons- most light is created from the direct sun radiation as well as reflection from other surfaces. Full analysis of the observation as well as daylight performance is shown in Appendix IV-b

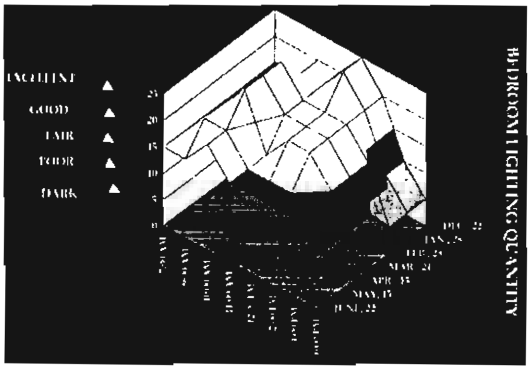

Figure 10: Daylight Performance for Bedroom.

5.3. Kitchen:

There was no pictures that show any direct light coming through the kitchen window that overlooks courtyard. The outer window - facing south- is the main natural lighting source for the kitchen. All direct light is entering kitchen through the outer window. Most direct light is penetrating between 11:00 AM to 2:00 PM (Figure 11-12).

Having two openings -one overlooks courtyard and the other overlooks south- created a considerable percentage of illumination that - in turn- made kitchen brighter than any other space as shown in Appendix IV-c. At 2:00 PM is the time that a lighting quantity hierarchy is sequenced from June until December.

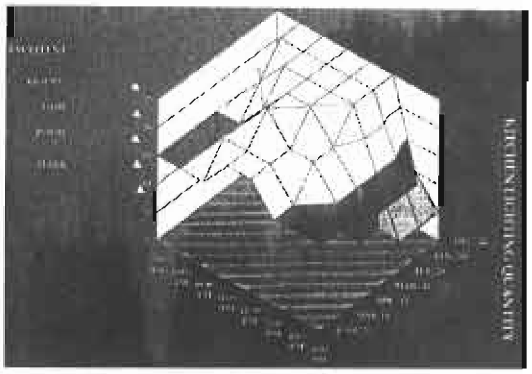

Figure 11: Daylight Performance for kitchen.

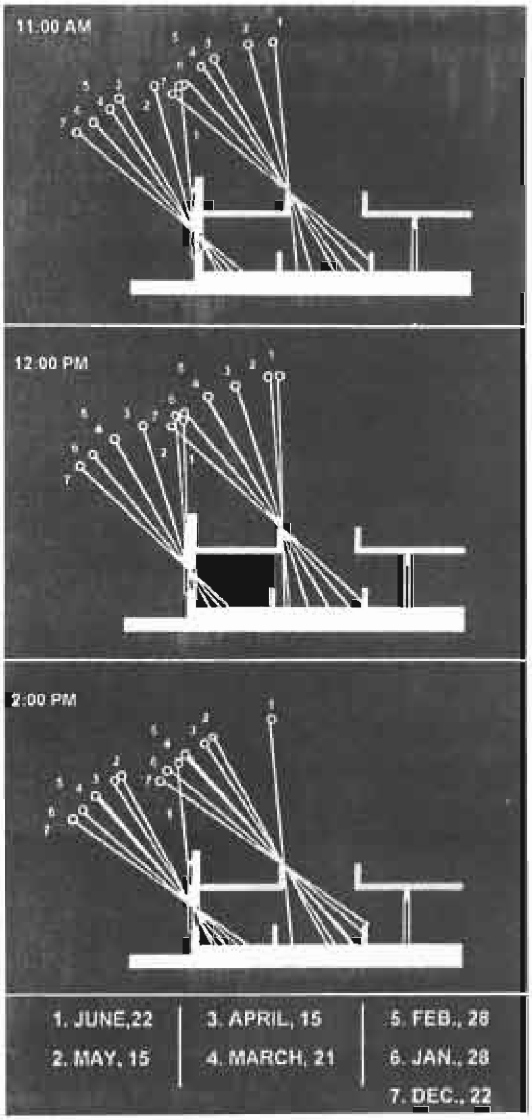

Figure 12: Sun Angles and Light Penetration through kitchen.

5.4. Corridor:

The observation showed that direct sun light is mostly penetrating the corridor window (on the southern direction) during winter seasons (preferred time). Most direct sun light entered between the hour of 11:00AM to 2:00PM. The record of an excellent lighting distribution was found at the 10:00AM's of the entire year.

In June and May, the maximum lighting percentage occurs between 11:00AM to 2:00PM, meanwhile, it is the time that the structure is consuming it's maximum percentage of energy consumption (Appendix IV-d).

Although the sun latitude and azimuth are different, direct sun light is penetrating the window corridor at 11:00 AM for the whole year (Figures 13-14).

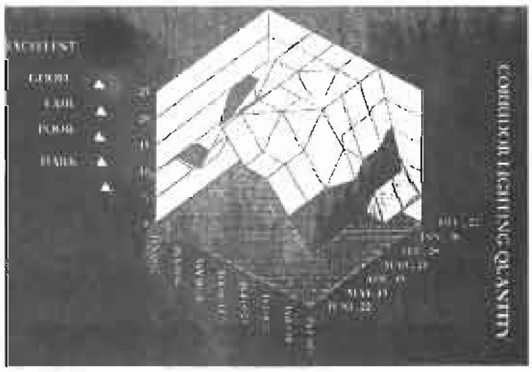

Figure 14: Daylight Performance for Corridor.

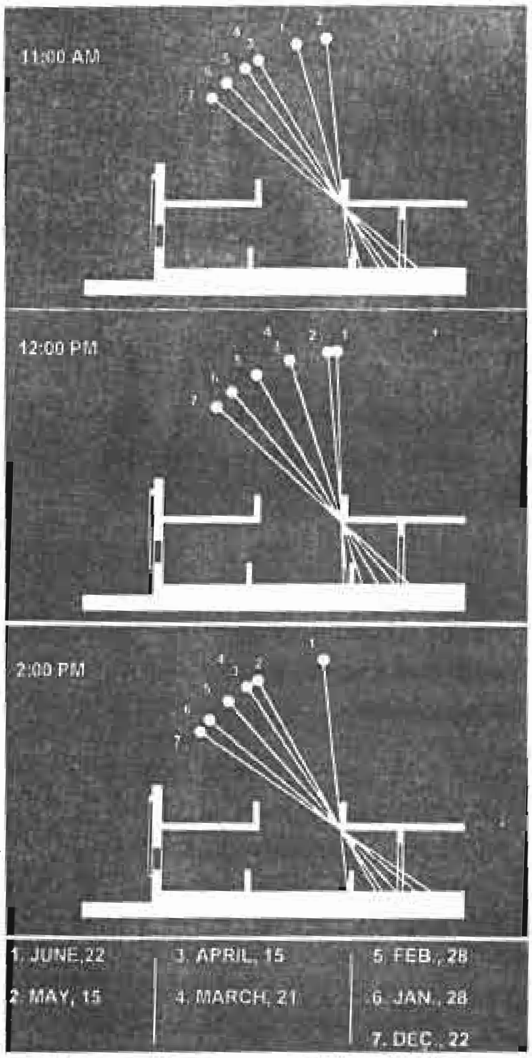

Figure 13: Sun Angles and Light Penetration through corridor.

6. Recommendations:

6.1 Living Room:

Despite that there is a large window in the living space overlooks the courtyard, living room is considered to have the least amount of direct sun light among all other spaces. This is because the window faces west. Only sun at 2:00 PM and partial radiation at 4:00 PM is entering the living space.

- **Using shading device:** Using the horizontal louvers as shown in figure 15a, it was possible to prevent summer months June, May, April and March. On the other hand, Lowering the height of the courtyard parapet and external wall parapet, winter radiation entered the living room.

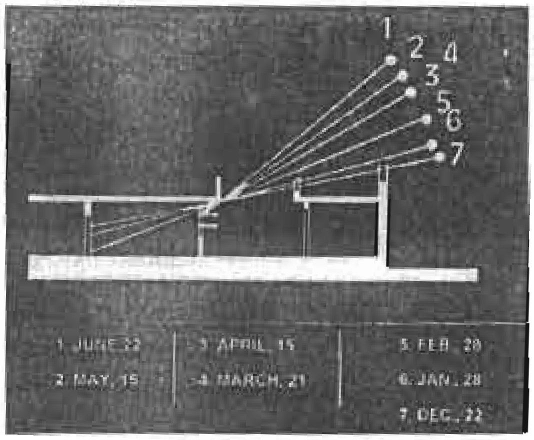

Figure 15-a : Living Room Alternate Solutions.

- **Applying an overhang:** Extending the roof slab towards the courtyard with 45cm long will protect living space during summer and allow winter radiation as shown in figure 15b.

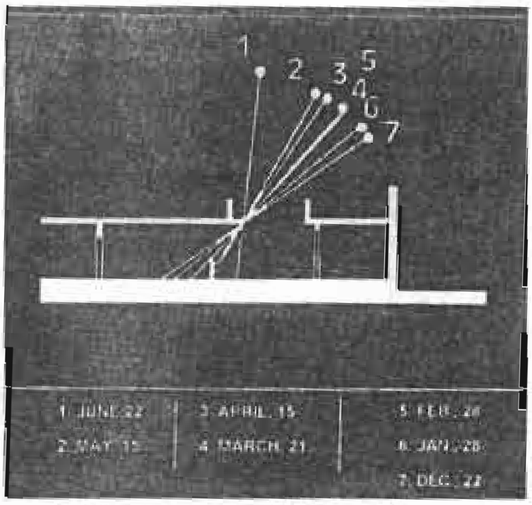

Figure 15-b : Living Room Alternate Solutions.

6.2 Bed Room

The window opening of the bedroom if framing the wall overlooking courtyard. Side openings are more exposed to the radiation than upper one. The light is penetrating bed room at 9:00 AM and 10:00 AM most of the year.

- **Using shading device:** A horizontal device can be used to protect bedroom from summer radiation but not the winter one. Spaces between the shading device louvers are more than that in corridor about 10 cm (Figure 16). This is because the sun angles that penetrates bedroom are lower than those of corridor. This solution will prevent all summer direct sun light, meanwhile, permits winter sun radiation.

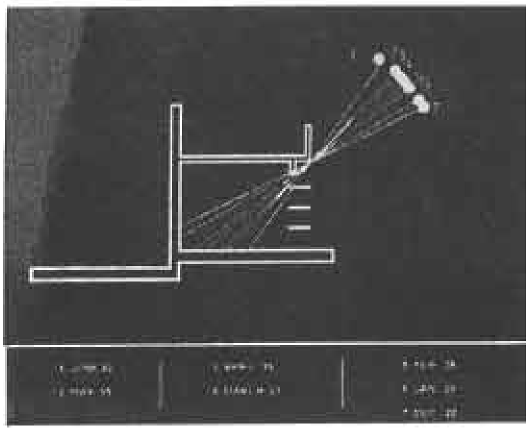

Figure 16 : Bed Room Alternate Solutions.

6.3 Kitchen:

Kitchen is influenced by the sun radiation coming from the southern window more than the window overlooking courtyard. Thus, the modification should be made on the window on the southern direction.

At 2:00 PM, all sun radiation's are penetrating to the kitchen except in June. This necessitates the modification of this window to prevent the penetration of summer months - May, April, and March.

- **Using a shading device:** The sun latitude in March is 57°. The design of the device is based on the month of March because March sun angle is the one that divide the winter and summer sun angles.

Winter is lower and summer are higher. The shading device is designed by the following equation(9):

$$\mathbf{D = H / (\tan A)}$$

Where:

- D is the depth of the shading device.
- H is the height of the shading device from the window base
- A is the angle of sun latitude.

$$\mathbf{D = 120\ cm / \tan 57° = 77.9cm}$$

Thus, as shown in figure 17a-17b theta, the shading device allows winter seasons sun radiation's and prevent the months of summer seasons.

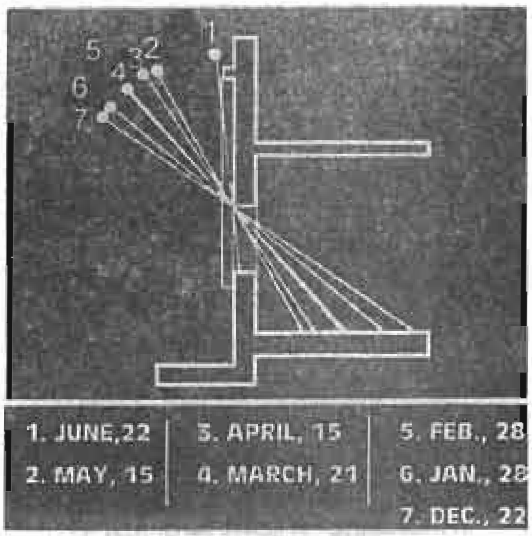

Figure 17-a: Kitchen Shading Device Alternatives.

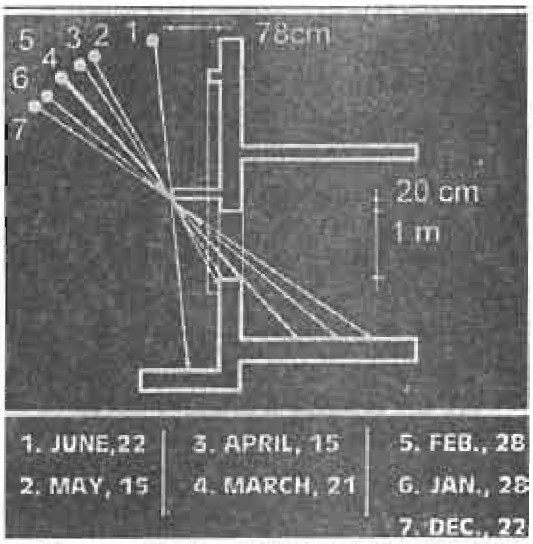

Figure 17-b: Kitchen Shading Device Alternatives.

6.4 Corridor

Corridor is affected by the most direct radiation that penetrates the house. Because of the large opening on the southern direction, corridor allows numerous amount of sun radiation from 11:00 AM until 2:00 PM. It requires a redesign that can reduce the percentage of direct light and to control the energy consumption of the building initially during summer time.

- **<u>Modify the window size</u>**: The existing window size is approximately 5m2. This means that changing window size can reduce the edge. Figure 18a shows that resizing the window allowed permits daylight during winter while protects against summer.

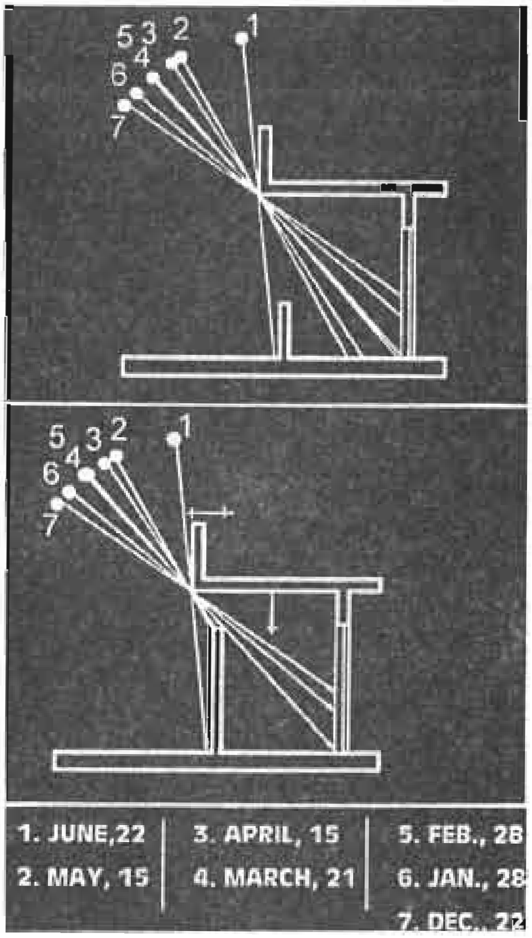

Figure 18-b: Corridor Design Alternatives.

- **<u>Using shading device:</u>** This method can be a solution too. In this case, the window is left in it's original size but a hanging shading device is designed in a way that allow winter radiation's to penetrate in between the device where winter radiation are not allowed (Figure 18b).

Thus, the most optimum solution is the modification of the window size or using shading device to enhance daylight performance with out increase thermal performance of the building.

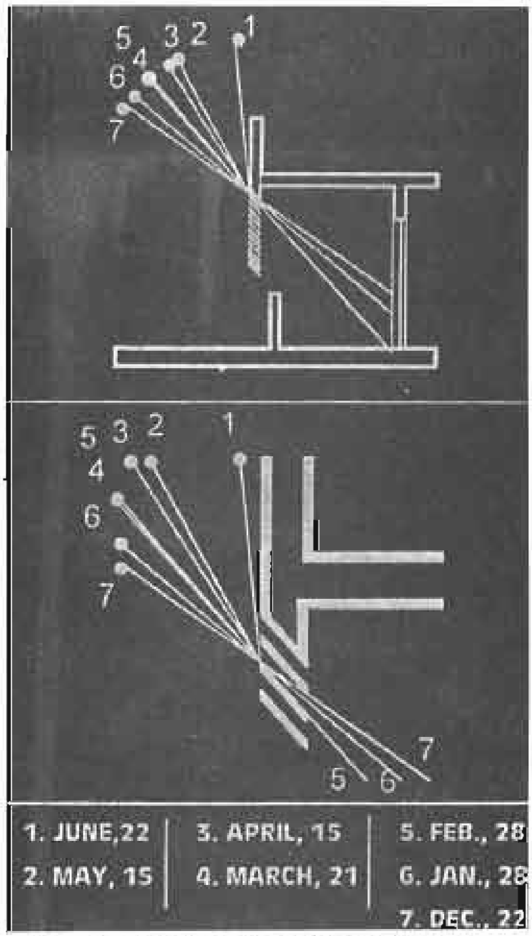

Figure 18-b: Corridor Design Alternatives.

7. Conclusion:

- An intensive analysis of the sun radiation penetration can considerably enhance the daylight performance within building enclosure and, at the same time, control the total energy consumed by the structure. As a result thermal comfort is enhanced and economical cost is cut down.
- If the angle, size, location and orientation of the shading device is not studied at early stages of design, the final product of the device may be useless and uneconomical.
- The courtyard house design concept is beneficial in term of daylight performance. But, a designer can reach an optimum form and size of the courtyard when considering sun path diagram of the area where the house will be established.
- Lighting reflection from other surfaces may enhance or reduce the daylight performance of the space and must not be neglected.
- A designer can increase or decrease the occupants comfort within the structure depending upon his understanding of the solar data and sun path.

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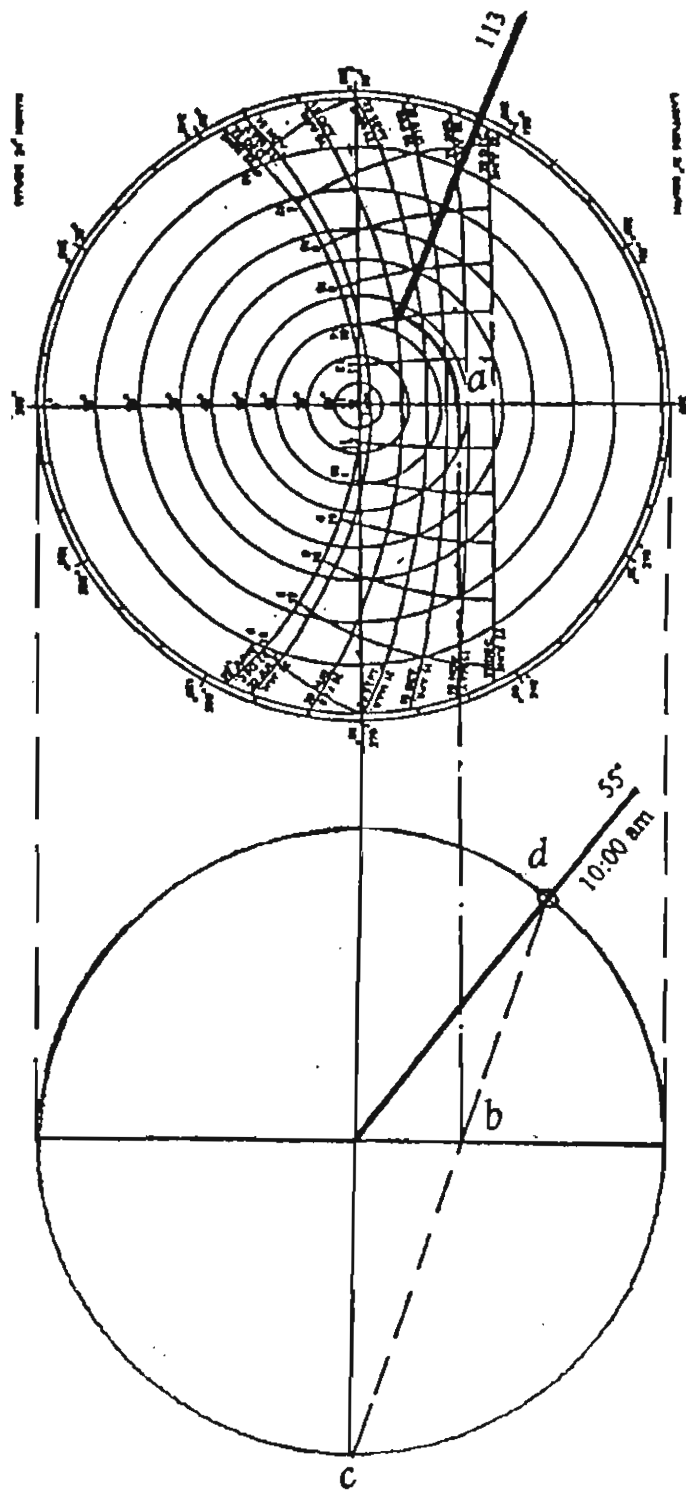
Appendix 1: Calculation Methodology of Determining the Sun's Positions.

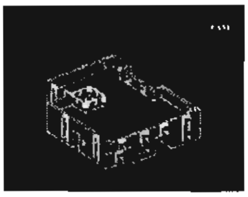


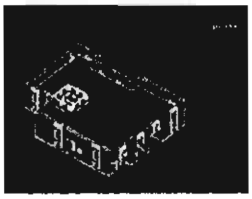
Appendix II: Table of Azimuth and Latitude Data for Selected Days.

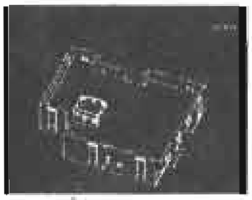
Time	28 JAN.		28 FEB.		21 MAR.		15 Apr.		15 May		22 June		22 DEC.	
	Latitu. Angle	Azimu. Angle	Latitu. Angle	Azimu. Angle	Latitu. Angle	Azimu. Angle	Latitu. Angle	Azimu. Angle	Latitu. Angle	Azimu. Angle	Latitu. Angle	Azimu. Angle	Latitu. Angle	Azimu. Angle
.00 AM	7	110	12	105	15	97	17	88	20	72	26	74	3	115
.00 AM	30	128	37	120	45	112	43	102	47	86	55	81	26	132
0.00 AM	40	140	48	137	57	124	55	113	61	92	70	85	35	145
1.00 AM	47	158	55	153	60	145	62	133	74	101	84	91	40	160
2.00 AM	50	180	60	180	72	180	74	180	85	180	88	180	43	180
.00 PM	40	220	48	227	57	235	55	247	61	270	84	272	35	210
.00 PM	20	240	15	250	30	255	31	266	35	280	40	287	16	236
.00 PM	0	0	0	0	1	270	5	279	8	290	10	292	0	0

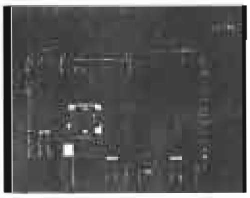
Appendix III: Picturing Sample of the Model for one Day.

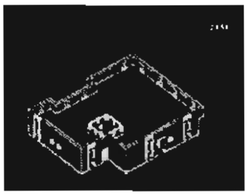
PICTURING THE MODEL

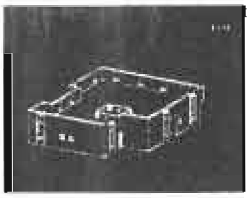












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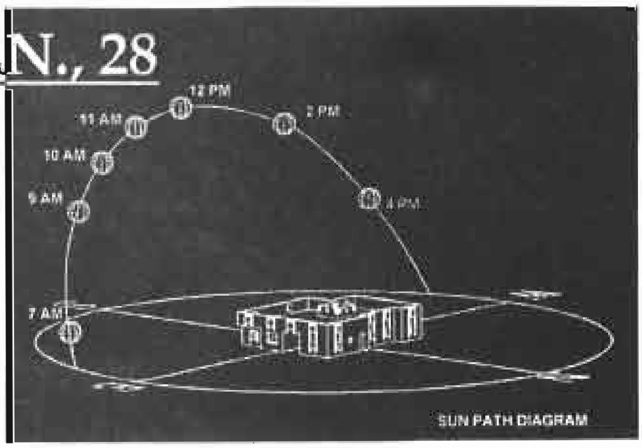
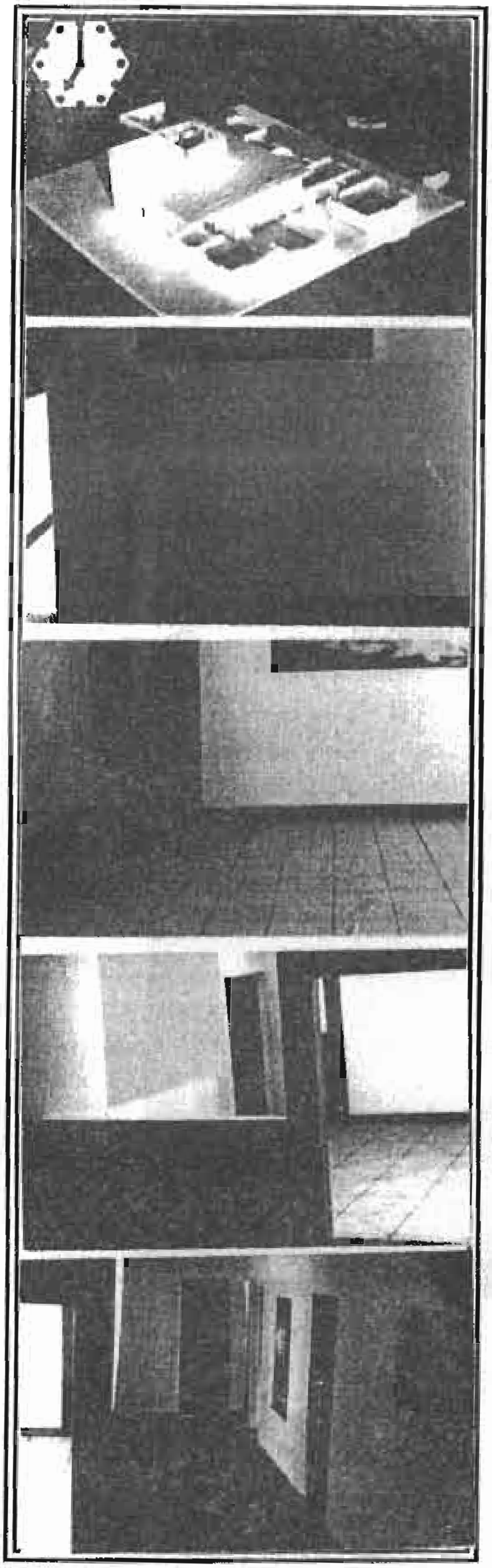
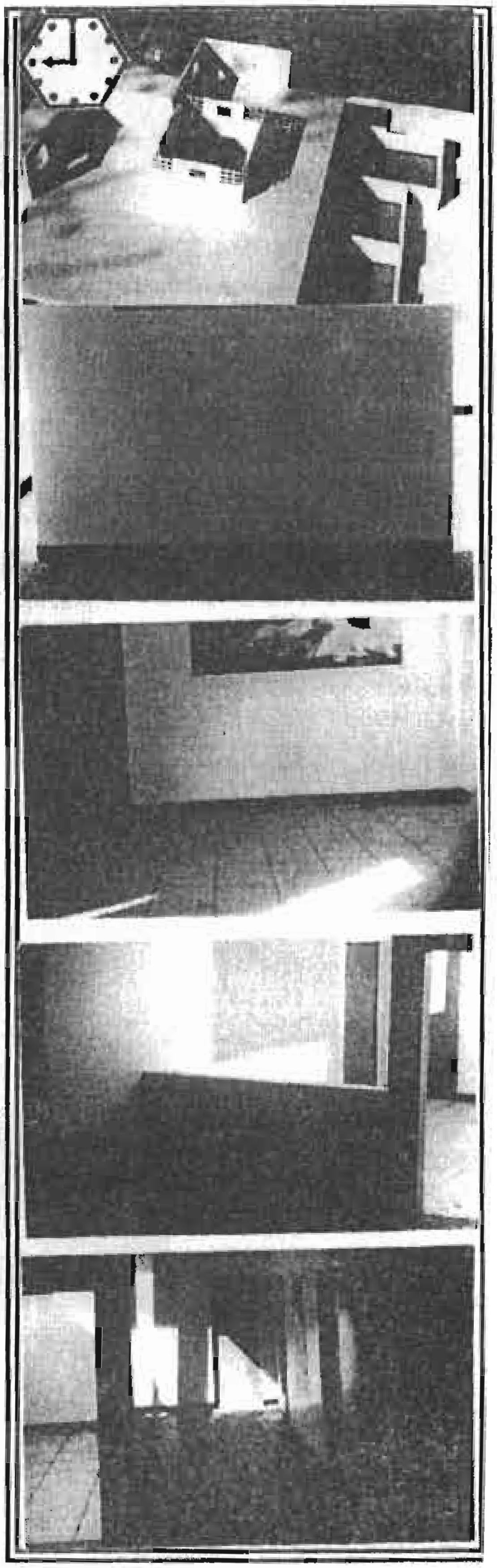
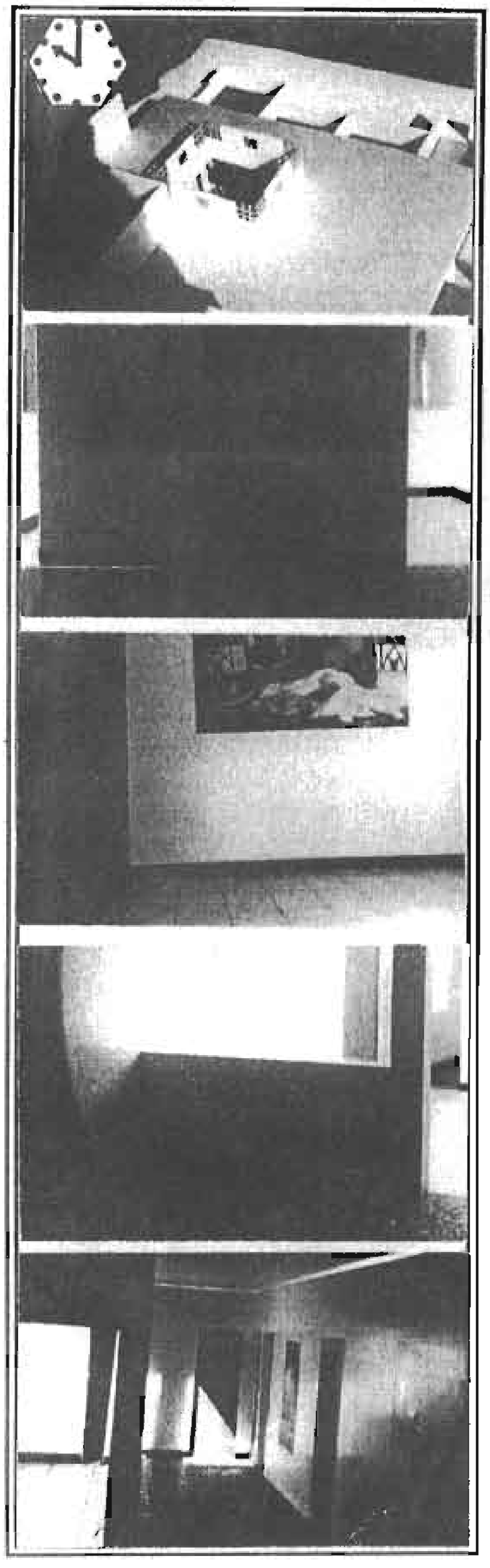
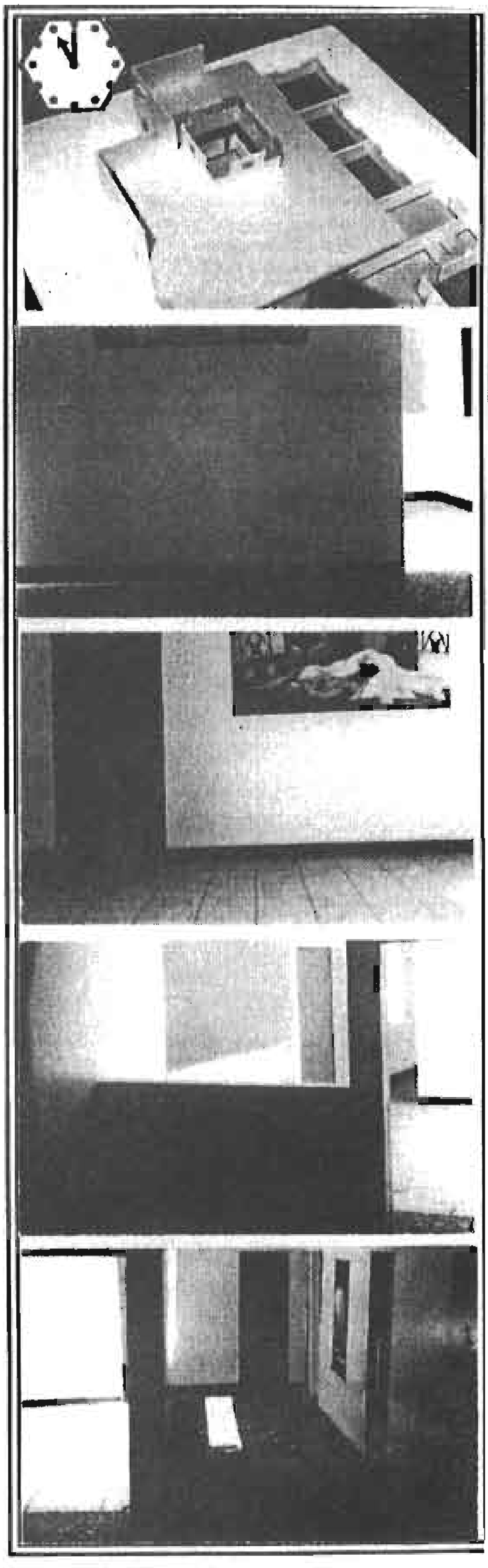
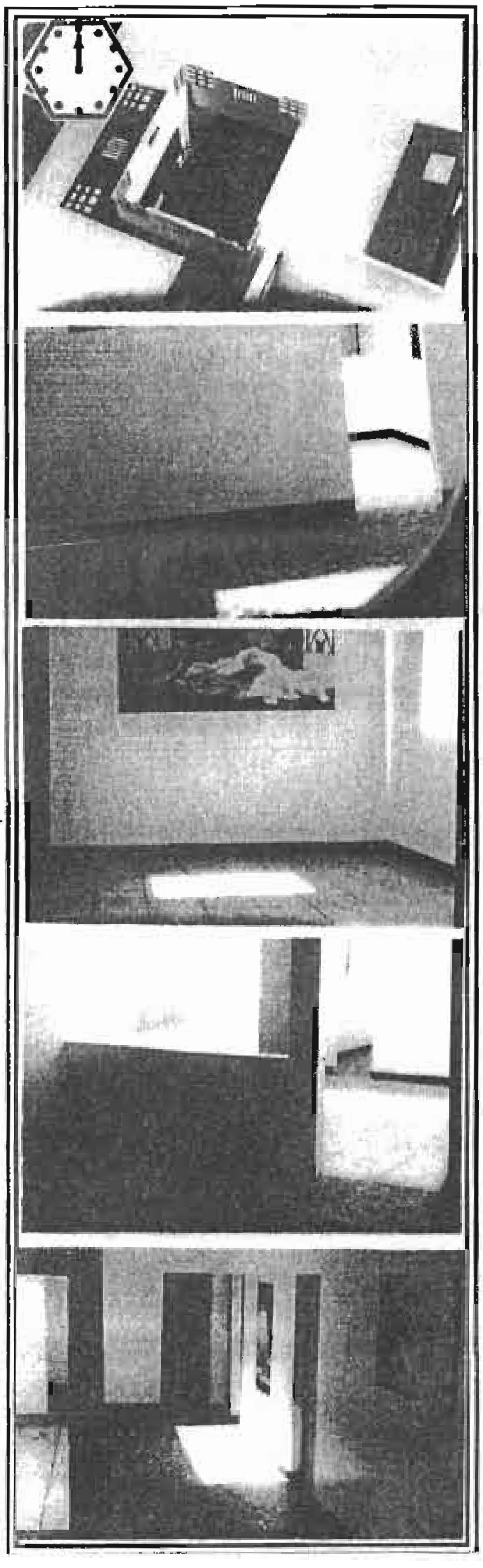


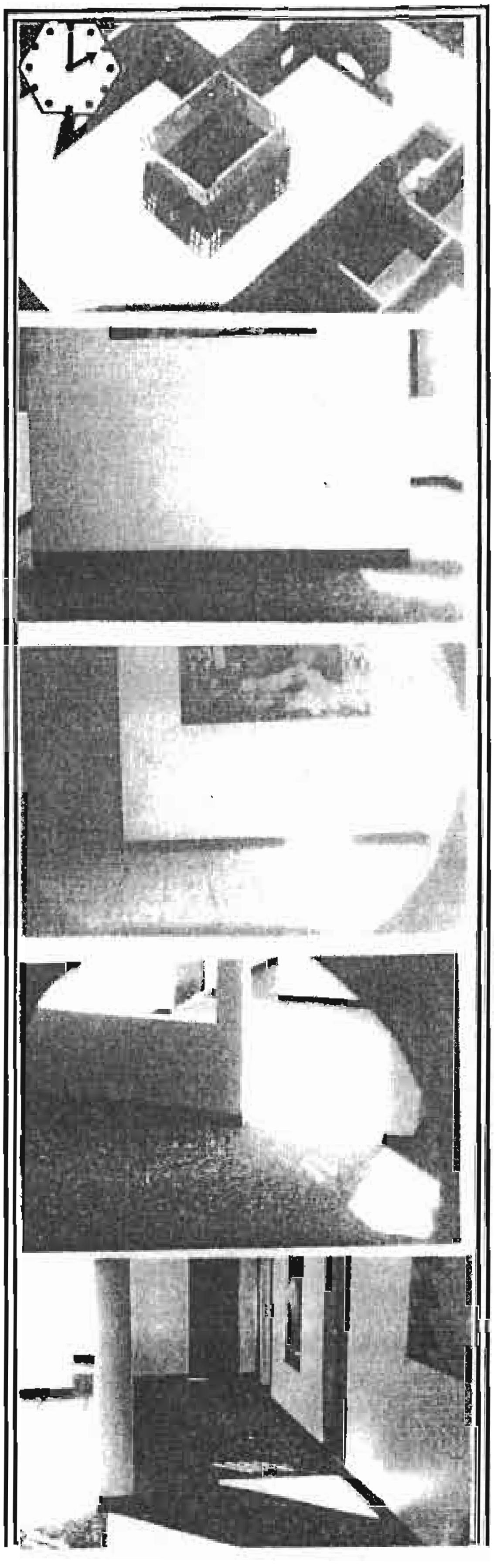




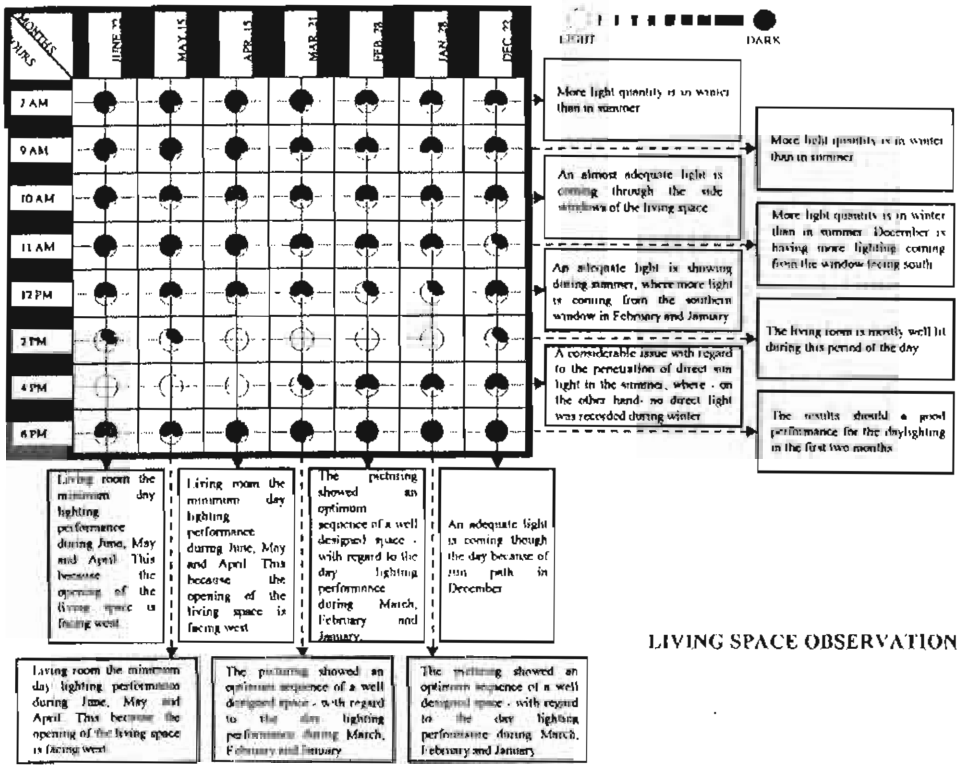




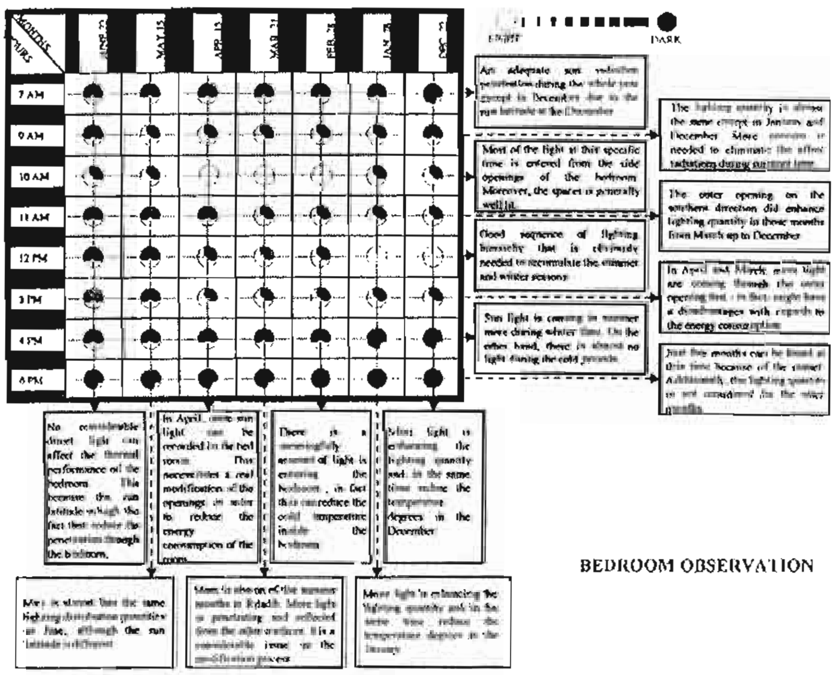




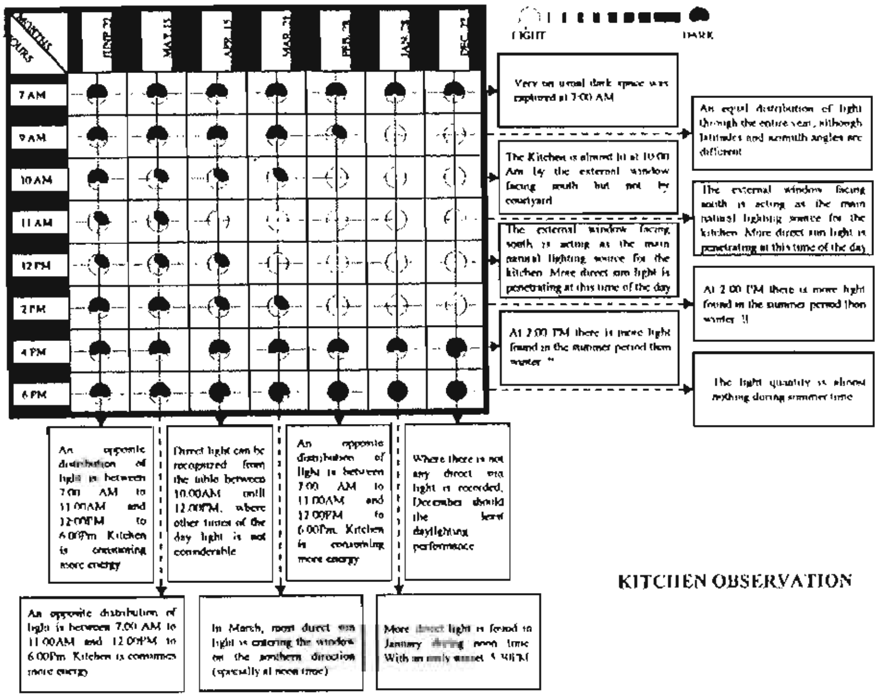
Appendix IV. Observation analysis charts for lighting pictures within the four selected spaces:



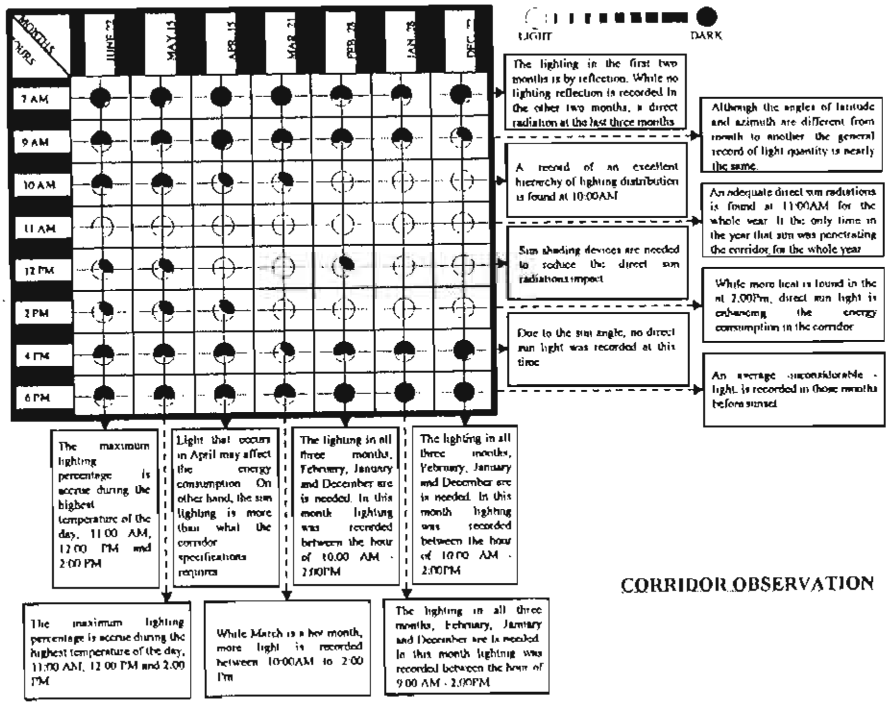
Appendix 4-a : Observation of living space.



Appendix 4-b : Observation analysis chart for bedroom.



Appendix 4-b : Observation analysis chart for kitchen.



Appendix 4-b : Observation analysis chart for corridor.