ISSN No:-2456-2165

Daylighting
Optimizing the Illumination Level in Light Wells by Making Use of the Correct Relation of their Sides

Carlos Daniel Rivas Kubler
Universidad Científica del Sur: Facultad de Arquitectura y Urbanismo Ambiental
UCSUR
Lima, Peru

Abstract:- This study began because of the necessity to know how the traditional light well works and arrive to a simple rule that architects can apply at the moment of designing buildings, mainly multi-storey apartment buildings, in which except for bathrooms, all rooms need an outdoors relation.

This is important not only because it involves architectural problems but also legal ones, we don't have to forget that light wells are usually common areas in multi-storey apartment buildings and each one of the apartment owners has rights over them, for this reason, the simplest solution would be the best.

Some of the conclusion from this investigation were:
A compact form of the light well is the best way to optimize daylighting.

Both sides of light wells provide the same illumination for their windows despite the proportion of the sides.

One big light well provides better illumination rather than many small light wells that sum the same area.

These conclusions can be taken as considerations architects can use at the moment of designing because they give a simple tool to proportion light wells and design the rooms around them.

Also, this study arrives to other conclusions, first that it is not possible to use a rule of three in order to study daylighting with scaled models; and that the decay of illumination inside light wells is not constant, there is a small decay in the top and a very pronounced in the bottom.

Those conclusions are important because this work was thought to be the first step for further experiments with much more sophisticated models and equipment, and also more expensive, so a well-done budget based on the design of models on bigger scales is needed.

Although nowadays the use of computer simulations in order to study daylighting has many advantages, such as cost and time, the most reliable conclusion can only be obtained from an experiment because as it was known since the first days of computing, the machine only will solve the equations and follow the program, it will depend on the data and the program gave by humans if the result is correct.

Keywords:- *Light Well, Void, Courtyard, Daylight, Scaled Models.*

I. INTRODUCTION

To create compact cities, reduce the energy and space used in transportation, and increase the square-meter value, daylighting has become an important topic in sustainable buildings. Daylighting not only reduces the use of artificial light, electricity, and fossil fuels (depending on the country) but also promotes the health of users.

Light wells represent one use of urban areas, so a good strategy to design light wells with accurate proportions will optimize urban land, enabling us to have more green areas such as parks or gardens. On a larger scale, light wells promote the preservation of natural and agricultural areas.

An architect needs to have a clear idea about how to solve daylighting, mainly in multi-storey apartment buildings; however, some countries have no codes that establish the dimensions of light wells, while others have codes that have no relation to reality, for example, stipulating that the light well length has to be a portion of its depth while keeping the same width.

In this paper, we describe a correlational investigation made with scaled models with the aim of identifying the optimal relationship between the length, the width, and the depth of light wells. Our most important conclusions are as follows:

- There is a relation between the illumination level and the depth of the light well.
- There may or may not be differences in the illumination levels on either side of a light well at the same depth.
- A light well with a bigger area provides better illumination.
- Compact light wells are more efficient than slender ones.
- Studies with scaled models show that there is no geometrical relationship between the dimensions and the illumination level but rather a logarithmic relationship.

This is a correlational investigation conducted as the final project for a master's degree. The main idea was to identify a simple way to optimize the open area of a plot in order to provide daylight to all rooms of a building, specifically multi-storey apartment buildings, and to develop a simple formula that architects can use to design buildings with good illumination.

Unfortunately, some countries have no codes that specify the dimensions of light wells, while others have codes that are not compatible with information published in scientific journals or with what I have seen in my study with scaled models.

II. LITERATURE REVIEW

Light wells have been used for a long time mainly in multi-storey apartment buildings as a solution to provide daylight from outdoors directly to all rooms because most multi-storey apartment buildings are built on small plots with a small frontage compared to their total area.

Daylighting reduces emissions of CO2 in regions where fossil fuels are used to produce electricity and reduces the use of electric lighting during the day. This is important not only because lighting represents 19% of electric energy consumption but also because retrofitting lighting systems is so expensive that the increase in the net value after the retrofit does not always improve the illumination comfort [1]. Significantly, urban areas, where light wells are most needed, represent 75% of global energy consumption and 80% of greenhouse gas emissions. This is the reason why one of the priority strategic objectives of the European Union is innovation in renewable energies and reduction in energy use [2]. On the other hand, daylighting usually represents heat gains and an increase in the energy required to cool a building, so sometimes daylighting results in an increase in energy demand instead of a reduction in energy demand [3]; however, as this is a preliminary experiment, we did not consider heat gains in order to reduce the variables.

Although nowadays tubular daylighting devices are available, only natural daylight through windows can provide overall satisfaction with the luminous environment [4]; natural daylight has positive effects on health, well-being, circadian rhythms, productivity, mood, and alertness [5] [6]; a diffuser that looks more like a spotlight than a window cannot ameliorate the feeling of being enclosed.

During the 1990s in Japan, a new solution to provide daylight in 30- to 40-storey multi-family buildings appeared. The use of one big light well or void in the middle of the building was studied in "Environmental Assessment of Light Wells in High-Rise Apartment Buildings" [7]; unfortunately, this was not a correlational study but a casuistic study that made use of a survey to investigate the satisfaction of the occupants with the luminous environment within the building. Another problem with this study is that it does not eliminate other variables such as the age of the occupants.

It is very challenging to conduct a correlational study in a building; thus, one solution is to make use of models. One study that does so is titled "Light Wells in Residential Buildings as Complementary Daylights Source" [8]; this study compares individuals light well (one small light well for each apartment) with common light (One big light well for all apartment) wells in buildings. Another study that makes use of models, titled "Assessing Daylight Luminance Values and Daylight Glare Probability in Scale Models" [9], does not study illuminance but rather glare probability.

Finally, some studies make use of computer simulations. These include "Improving Daylight Performance of Light Wells in Residential Buildings: Nourishing Compact Sustainable Urban Form" [10] and "FAST Energy and Daylight Optimization of an Office with Fixed and Movable Shading Devices", [11] which both investigate daylighting, heating, and cooling in Southern Europe using Daysim software. Another study, titled "Improving the Daylighting Performance of Residential Light Wells by Reflecting and Redirecting Approaches" [12], evaluates the use of a mirror to reorient daylight in light wells. A further study in this area is titled "The Study of Effective Factors in Daylight Performance of Light-Wells with Dynamic Daylight Metrics in Residential Buildings" [13].

However, the most important study to mention here is titled "Daylight Optimization Through Architectural Aspects in an Office Building Atrium in Tehran [14]", which is not only the most recent study but the one that is most similar to the current study; the main difference is that in the current study, scale models are used, which is important because it will help us to understand the differences and similarities in the results of these two studies.

Although there are studies about the prediction of Day Factor (DF) such: Daylight prediction in atrium buildings [15] or Lighting design in courtyards: Predictive method of daylight factor under overcast sky conditions. [16] These predictions are mainly for a specific point in the light well. We have to consider DF as an instrument to study daylighting and not an easy rule to follow at the moment of designing; also these studies mainly those with scale models take for granted that the daylight factor (Which is for definition the relation between the illumination level in the top and the illumination level in the floor we are analyzing.) keeps the same value in models with the same proportions but different scales.

III. HYPOTHESIS

As the main idea of this work is to find out the best way to optimize the open area inside the plot in order to daylight buildings, four different hypotheses were formulated for this.

A. It is possible to use scaled models in order to study daylighting.

This is the most important because it is the basement of the rest of the investigation, it is needed to know if there is a relation or which class of relation there is in scaled models when these are used to study daylighting or there is a problem of scales similar to the one about the ant and its weight in which if we resize the ant by two its weight will increase in eight.

B. Narrower light wells are more efficient than square plan light wells.

The main reason for this hypothesis is that the Peruvian building code (RNE) [17] tends to this kind of light wells (2.20m width and a length equal to the third or fourth part of the depth depending on the use of the rooms) so as taller the building the longer the light well and the more difficult problem to be solved. Sometimes the light well is so long that it doesn't fit in the plot, or is too long that increases too much the circulation inside the apartments.

C. Both sides of the light wells provide the same illumination level.

The most important problem for an architect at the moment of designing and solving daylighting in core spaces is taking advantage of all daylight inside the light well, for this it is important to know if each part of the light well can provide the same illumination.

D. There is a relation between the area of the light well and the illumination level.

Although this seems obvious, we cannot take anything for granted, and there should be a limit in the illumination the light well can provide, if there is a light well as big as a field in the stadium and it increases its area in one square meter, the illumination won't increase because it already has aimed its limits, on the other hand, if there is a light well as tall as an industrial chimney and then increase its height in one-meter illumination won't decrease significantly, and maybe it won't be perceived.

IV. METHODS

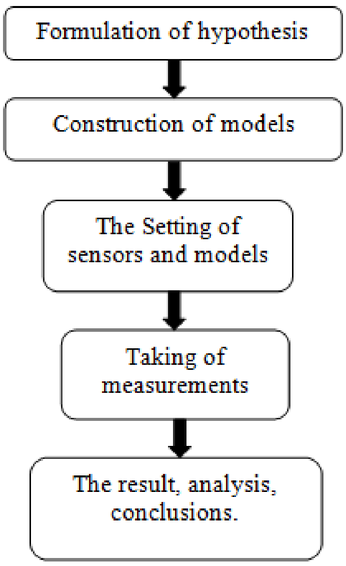
Although nowadays it is much more common to make use of computer simulation programs to study illumination, this kind of investigation cannot be taken for granted because even although these programs have become with time more and more sophisticated we don't have to forget that they only output data from those we have already input.

That is why this study can be considered a validation study [18]. The main problem in this investigation was having a low budget, however as it can be considered an exploratory investigation because it is one of the few made with scaled models, and the fact that many measurements had to be taken at the same time.

First of all, it is important to say that this is a preliminary study in order to find if it is possible to make more sophisticated experiments, with a higher budget and also which would be the new hypothesis, this is the main reason why sensors were made using photovoltaic cells and a voltmeter so that the units used were volts instead of lux, and that is why the comparison was made using the quotients between the measurement in at the same depth and the measurement at the top, that here we will call DF or daylight factor because defined as "*the ratio of the internal horizontal illuminance at some arbitrary point in a space to the unobstructed (external) horizontal illuminance from a hemisphere of sky".* [19]

All models were in the same tone of white, sensors were stuck to the models leaving no space between the walls of the model and the sensors; all measurements were taken in only one morning on the same sunny day because some models were so big that it would have been impossible use electric light, also daylight is more powerful and easy to located relative to the model, finally, the measurements were compared in order to find out if there were significant differences, for this the ANOVA was used when there were more than three groups and the *Student t-test* when there were just two such when both sides have to be compared.

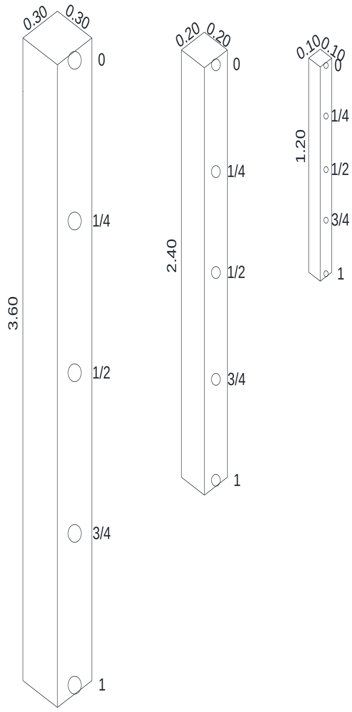
Flow chart of the methodology



In order to demonstrate the first hypothesis we are going to build three different models with the same proportion but different scale and take measurements at the same proportional depths compared with the measurement in the top of the light well, if there are no significant differences in the quotient at the same relative depth we are going to assume that there is a relation between scaled models, and it is possible to predict the portion of the illumination the light well provides at a determinate depth.

ISSN No:-2456-2165

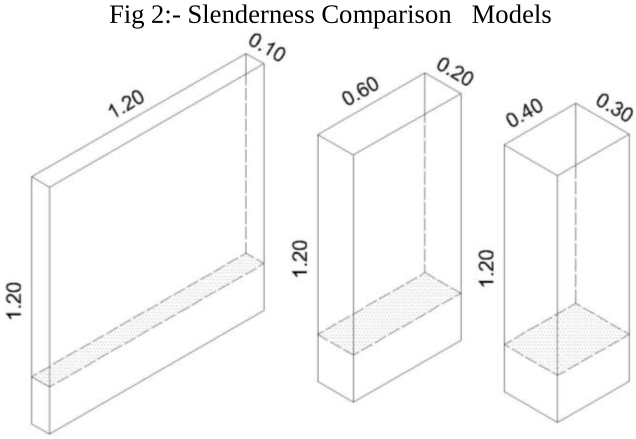
Fig 1:- Scale Proportionality Comparison Models



The figure shows the three models used in the experiment in order to demonstrate the first hypothesis and each one of the points in which the sensors were sets showing the relative distance to the top. As we can see the one in the middle is two times the size of the smallest and the biggest is three times the smallest.

For the second hypothesis, four different models with the same scale are going to build these will have the same plan area but with different proportions 1 to 12, 2 to 6, and 3 to 4, then we are going to take measurements at the same depth related to the measurement in the top of the light well, if there are no significant differences in the quotient at the same depth we are going to assume that there is no relation between sides and the illumination level.

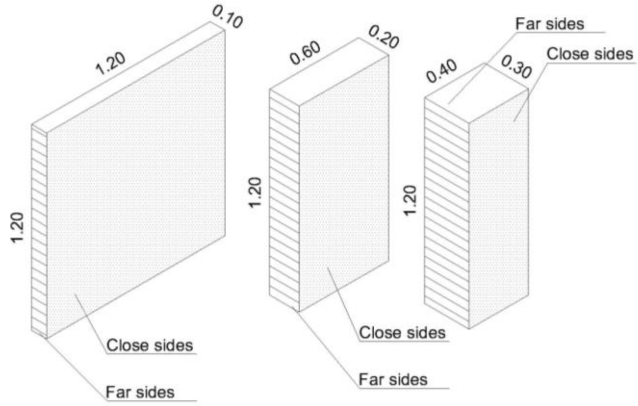
Fig 2:- Slenderness Comparison Models



The figure shows the four models used in the experiment in order to demonstrate the second hypothesis if Narrower light wells are more efficient than square plan light wells, each model have the same area (12), the depth change at the same proportion of the previous experiment, ¼, ½, ¾ and 1

For the third hypothesis the same models are going to be used, the idea here is to eliminate the variable of the area and keep only with the variable of the sides if there are no significant differences in the quotient at the same depth on both side at the same depth we are going to assume that both sides have the same illumination level.

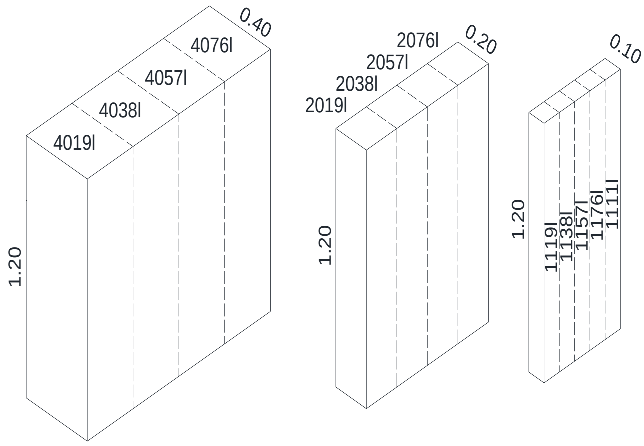
Fig 3:- Sides Comparison Models



The figure shows the four models used in the experiment in order to demonstrate the third hypothesis if Both sides of the light well provide the same illumination level, each model have the same area (12), the depth change at the same proportion of the previous experiment, ¼, ½, ¾ and 1

Finally, models with different areas have to be compared and if a significant difference between the measurements taken at the same depth is found we are going to assume as true the hypothesis that the biggest area the highest illumination level.

Fig 4:- Area Comparison



The figure shows all models variants used in the experiment in order to demonstrate the fourth hypothesis, the code portrays the area of each model EG 4019L means that it has 0.40m wide and 0.19m long, and 4076L means that it has 0.40 wide and 0.76m long.

V. RESULTS

From this investigation, we have to conclude that it is no possible to study daylighting with models using the rule of three because after comparing the quotients between the measurement at the same depth and the measurement at the top of the three models using the student's t-test there were no significant differences.

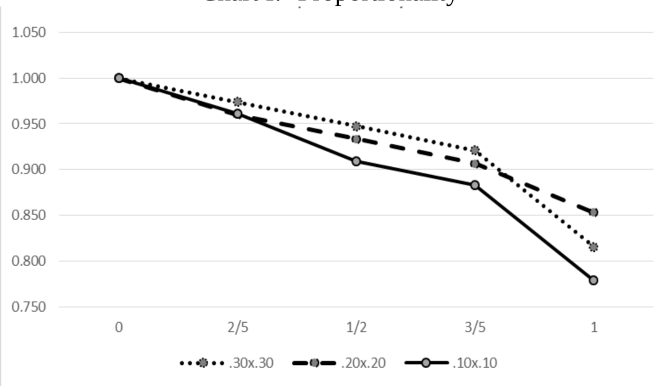
This means that one light well with 3.00 m x 3.00 m x 9.00 m depth won't have the same quotient of illumination of a 3.00 cm x 3.00 cm x 9.00 cm depth; this is the reason the study did not conclude in a formula or rule that predicts the illumination level in light wells.

Table 1:-Df Of The Scale Proportionality Models

Relative depth	.30x.30	.20x.20	.10x.10
0	1.000	1.000	1.000
2/5	0.974	0.960	0.961
1/2	0.947	0.933	0.909
3/5	0.921	0.907	0.883
1	0.816	0.853	0.779

This table shows in the columns the three models used describing their sides (EG 0.30 x0.30) and the relative depth in the rows. The values are the relation between the measurements in the relative depth over the measurement in the top.

Chart I:- Proportionality



In abscises there are the proportional depths and in the ordered the DF (daylight factor), each curve represents the decay of the three models.

Table 2:- ANOVA Analysis of Scale Proportionality Models

Data Summary				
Groups	N	Mean	Std. Dev.	Std. Error
0.30 x0.30	5	0.9316	0.071	0.0318
0.20 x0.20	5	0.9306	0.0554	0.0248
0.10 x 0.10	5	0.9064	0.0844	0.0378

ANOVA Summary					
Source	Degrees of Freedom DF	Sum of Squares SS	Mean Square MS	F-Stat	P-Value
Between Groups	2	0.002	0.001	0.2005	0.821
Within Groups	12	0.0609	0.0051		
Total:	14	0.063			

This table shows the result of the ANOVA analysis as it can be seen the P-value is 0.821 over 0.5 so we have a significant difference

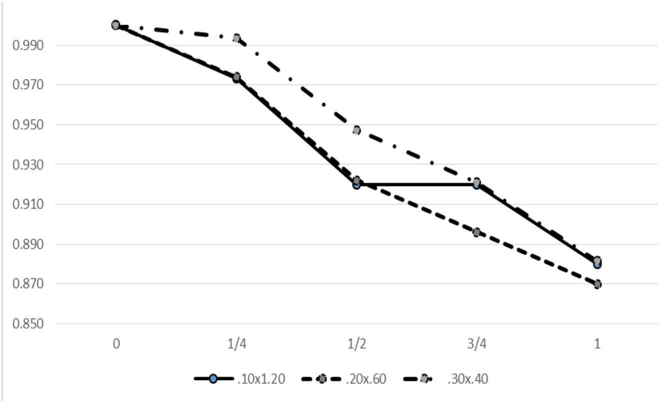
After comparing all the models made in order to demonstrate the second hypothesis, there were found a significant difference between the quotients at the same depth and the light well that had the best performance was the one that has its side in relation of three to four.

Table 3:- D.F. of the Slenderness Models

Relative Depth (total 1.20)	0.1x1.2	0.2x0.6	0.3x0.4
0	1.000	1.000	1.000
1/4	0.973	0.974	0.993
1/2	0.920	0.922	0.947
3/4	0.920	0.896	0.921
1	0.880	0.870	0.882

In this table, the columns show the dimensions of both sides of each model and the rows the relative depth, the results are the quotient between the measurements in the relative depth over the measurement at the top of the model.

Chart II:- Slenderness



In abscises there are the proportional depths and in the ordered the DF (daylight factor), each curve represents the decay of the three models.

Table 4:- ANOVA Analysis of Slenderness Models

Data summary				
Groups	N	Mean	Std. Dev.	Std. Error
0.10 x 1.20	5	0.9422	0.0432	0.0193
0.20 x 0.60	5	0.9178	0.0663	0.0297
0.30 x .040	5	0.9446	0.0531	0.0238

ANOVA Summary					
Source	Degrees of Freedom DF	Sum of Squares SS	Mean Square MS	F-Stat	P-Value
Between Groups	2	0.0022	0.0011	0.3632	***0.7028***
Within Groups	12	0.0363	0.003		
Total:	14	0.0385			

This table shows the result of the ANOVA analysis as it can be seen the P-value is 0.821 over 0.5 so we have a significant difference

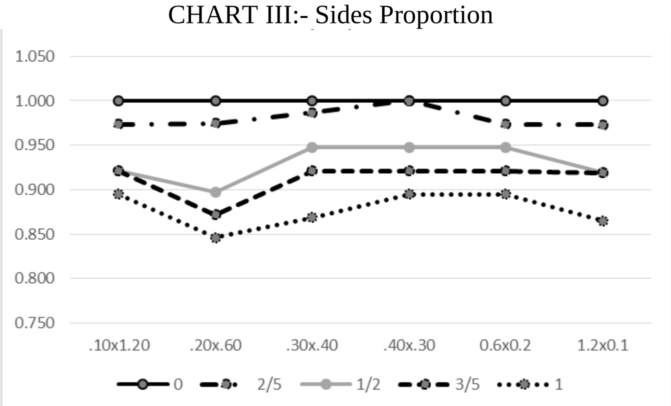
As there were found no significant differences between the quotients at both sides of the light wells at the same depth it is to assume that the illumination level is just the same in both sides of the light well.

Table 5:- D.F. of Area Models

Relative depth	0.1x1.2	0.2x0.6	0.3x0.4	0.4x0.3	0.6x0.2	1.2x0.1
0	1.000	1.000	1.000	1.000	1.000	1.000
2/5	0.974	0.974	0.987	1.000	0.974	0.973
1/2	0.921	0.897	0.947	0.947	0.947	0.919
3/5	0.921	0.872	0.921	0.921	0.921	0.919
1	0.895	0.846	0.868	0.895	0.895	0.865

Sides Proportion / Quotient - In this table, the columns show the dimensions of both sides of each model and the rows the relative depth, the results are the quotient between the measurements in the relative depth over the measurement at the top of the model. The measurements were taken on both sides of the models.

CHART III:- Sides Proportion



In abscises there are the proportional depths and in the ordered the DF (daylight factor),, each curve represents the decay of the three models.

The two-tailed P value equals 0.2912

By conventional criteria, this difference is considered to be not statistically significant

Confidence Interval

The mean of .10x 1.20 minus 1.20x0.10 equal 0.00700

95% confidence interval of the difference: from -0.00900 to 0.02300

Intermediate values used in calculations

T=1.2149

Df =4

Standard error of difference =0.006

Table 6:- Student's T Test For 0.10 X 1.20 To 1.20 X 0.10

Group	.10 x 1.20	1.20 x 0.10
Mean	0.94220	0.93520
SD	0.04324	0.05263
SEM	0.01934	0.02354
N	5	5

The two-tailed P value equals 0.0705

By conventional criteria, this difference is considered to be not quite statistically significant.

Table 7:- Student's T Test For 0.20 X 0.60 To 0.60 X 0.20

Group	0.20 x 0.60	0.60 x 0.20
Mean	0.91780	0.94740
SD	0.06633	0.04158
SEM	0.02967	0.01860
N	5	5

Confidence Interval

The mean of 0.20x 0.60 minus 0.60x0.20 equal 0.02960

95% confidence interval of the difference: from -0.06315 to 0.00395

Intermediate values used in calculations

T=2.4492

Df =4

Standard error of difference =0.012

The two-tailed P value equals 0.2109

By conventional criteria, this difference is considered to be not statistically significant

Confidence Interval

The mean of 0.30x 10.40 minus 0.40x0.30 equal 0.00800

95% confidence interval of the difference: from -0.02293 to 0.00693

Intermediate values used in calculations

T=1.4881

Df =4

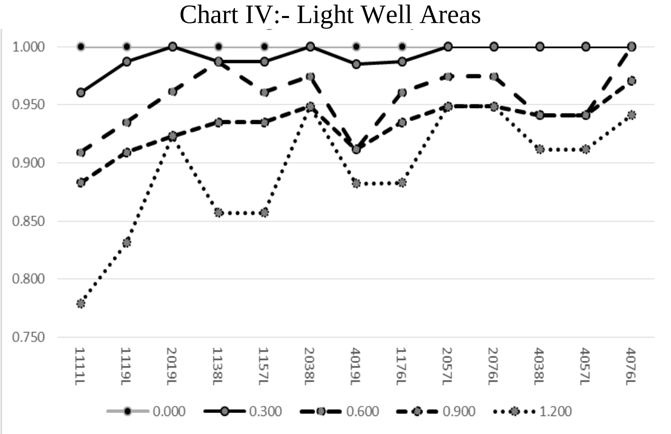
Table 8:- Student's T Test For 0.30 X 0.40 To 0.40 X 0.30

Group	0.30x 0.40	0.40 x 0.30
Mean	0.94460	0.95260
SD	0.05314	0.04701
SEM	0.02377	0.02103
N	5	5

This tables shows the result of the Students T-test comparing two light wells with the same area but with the sensor (or window) in opposite sides.

This result is very important because it shows that it is possible to solve daylighting in multifamily buildings using regular plan light wells, making use of both sides and reducing internal circulation.

Chart IV:- Light Well Areas



In this chart, we can see the illumination at the same proportional depths compared with the area of the light wells. The chart portrays the area of light well in abscises; DF (daylight factor) are in the order, each curve represents the decay at the de different depths 0 (on the top), 0.30(at ¼), 0.60(at ½), 0.90 (at ¾), 1.20(at the bottom).

Table 9:- ANOVA Analysis of Areas in Models

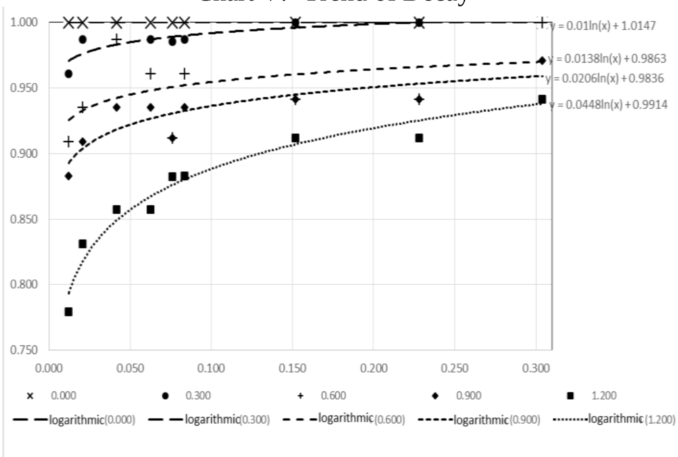
Data Summary				
Light well area	N	Mean	Std. Dev.	Std. Error
0.0836	5	0.95	0.0557	0.0249
0.0627	5	0.956	0.0586	0.0262
0.0418	5	0.934	0.0688	0.0308
0.0209	5	0.906	0.0841	0.0376
0.0121	5	0.974	0.0251	0.0112
0.152	5	0.974	0.0251	0.0112
0.114	5	0.974	0.0251	0.0112
0.076	5	0.96	0.04	0.0179
0.038	5	0.982	0.0268	0.012
0.304	5	0.958	0.0402	0.018
0.228	5	0.958	0.0402	0.018
0.152	5	0.938	0.0536	0.024

ANOVA Summary					
Source	Degrees of Freedom DF	Sum of Squares SS	Mean Square MS	F-Stat	P-Value
Between Groups	12	0.0251	0.0021	0.8778	***0.5739***
Within Groups	52	0.1237	0.0024		
Total:	64	0.1488			

This table shows the result of the ANOVA analysis as it can be seen the P-value is 0.5739 over 0.5 so we have a significant difference

We can notice that there is a clear trend although not all the points are in the same curve, this because as we have already seen area is not the only variable to consider but also the proportion of the sides.

Chart V:- Trend of Decay



This chart portrays the decay of the DF (daylight factor) in the order, each curve represents the decay at the de different depths 0 (on the top), 0.30(at ¼), 0.60(at ½), 0.90 (at ¾), 1.20(at the bottom), in the abscises there are the light wells ordered by their areas.

VI. DISCUSSION

This investigation is an approach to the problem of founding a law or a formula that can predict the illumination level depending on the dimensions of the light well. Its results can be resumed in:

- The deepest the light well the worst illumination.
- Compact light wells are more efficient than slender ones.
- The light wells provide the same illumination in its both sides.
- The biggest area of the light well the better illumination.
- It is better to solve the illumination with one big light well rather than two or more that sum the same area.
- Rule of three does not work to study daylighting with models.

According to the present study, it seems that the Japanese strategy for daylighting multi-storey apartment buildings using one big void in the middle of the building rather than many small light wells is a good idea, despite users' dissatisfaction in the lowest floors.

This work confirms the studies of Rastegari M., Pournaseri S., & Sanaieian H. [13] and Littlefair, P [14] in all three the conclusion was almost the same, the most regular plan the best illumination.

However, the most interesting conclusion is that it is not possible to study daylighting using a rule of three, so it is important to build more models in order to get the curve that represents the correct relation between different scales.

It is also important to consider more variables in the next experiments such as the number and size of the other windows in the light wells as well as the dimensions of the rooms attended by those windows, it seems that deeper rooms with bigger windows will demand more light that small rooms with small windows, leaving less light for the windows in the lowest floors.

Although it is well known that light colors have a higher reflection coefficient than dark colors it would be interesting to repeat the experiment considering this variable.

It is also important to consider in future experiments, different kind of glasses such as electrochromic [20], overcast conditions, color temperature of the daylight, and the diffusion of the light; for this, we also need to create a scale to measure it and make comparisons maybe a quotient between the illumination level in the shade and the illumination level in the light zone, but this is another topic.

Another topic we have to consider for the next experiments is the latitude, light wells will be more efficient in tropical latitudes with the sun next to the zenith rather than in sub-tropical zones with the sun facing façades instead of the light well.

REFERENCES

[1]. Bonomolo, M, Baglivo, C., Bianco, G., Congeedo P. M., Beccali, Marco. (2017), Energy Procedia 126 (2017) 171–178

[2]. Congedo, P. M., Baglivo, C. (2021), Implementation hypothesis of the Apulia ITACA Protocol at district level – part I: The model. Sustainable Cities and Society 70 (2021) 102- 931

[3]. Asfour, O. S. (2020). A comparison between the daylighting and energy performance of courtyard and atrium buildings considering the hot climate of Saudi Arabia. Journal of Building Engineering, 30 (2020) 101 – 299

[4]. Wang J., Wei M., & Ruan X. (2020) Characterization of the acceptable daylight quality in typical residential buildings in Hong Kong. Building and Environment, 182 (2020) 107094

[5]. Aries M., Aarts M., & Van Hoof J. (2013). Daylight and health: A review of the evidence and consequences for the built environment. Lighting Research & Technology, 2013; 0: 1–22

[6]. Editorial (2017) Advances on daylighting and visual comfort research. Building and Environment, 113 (2017) 1-4

[7]. Kotani H., Narasaki M., Sato R & Yamanakaa T. (2001). Environmental assessment of light well in high-rise apartment building. Building and Environment, 38 (2003) 283-289

[8]. Kristl Z. & A. Krainer A. (1999). Light wells in residential building as a complementary daylight source. Solar Energy, 65, (3), 197–206

[9]. Bodart M. & Cauwerts C. (2016) Assessing daylight luminance values and daylight glare probability in scale models. Building and Environment, 113 (2017) 210-219

[10]. Ahmed A.Y. Freewan∗, Anne A. Gharaibeh & Monther M. Jamhawi (2014) Improving daylight performance of light wells in residential buildings: Nourishing compact sustainable urban form. Sustainable Cities and Society 13 (2014) 32–40

[11]. Manzan M., & Clarich A. (2016) FAST energy and daylight optimization of an office with fixed and movable shading devices. Building and Environment, 113 (2017) 175-184.

[12]. Bugeat A., Beckers B. & Fernández E. (2020). Improving the daylighting performance of residential light wells by reflecting and redirecting approaches. Solar Energy, 207 (2020) 1434-1444

[13]. Ahadi A. A., Reza Saghafi M., & Tahbaz M. (2016).The study of effective factors in daylight performance of light-wells with dynamic daylight metrics in residential buildings. Solar Energy, 155 (2017) 679–697.

[14]. Rastegari M., Pournaseri S., & Sanaieian H. (2020) Daylight optimization through architectural aspects in an office building atrium in Tehran. Journal of Building Engineering, 101718

[15]. Littlefair, P., (2002), Daylight prediction in atrium buildings, Solar Energy, 73 (2002) 105-109

[16]. Acosta, I., Navarro, J., Sendra J.J. (2014) Lighting design in courtyards: Predictive method of daylight factors under overcast sky conditions. Renewable Energy, 71, (2014) 243e254

[17]. Ministerio de Vivienda, C. y. S. (2006). Reglamento Nacional de Edificaciones.

[18]. Ayoub, M., 2020. A review on light transport algorithms and simulation tools to model daylighting inside buildings. Solar Energy 198, 623–642.

[19]. Mardaljevic J. & Christoffersen J. (2016). Climate connectivity in the daylight factor basis of building. Building and Environment, 113 (2017) 200-209.

[20]. Catia Baldassarri C., Shehabi A., Asdrubali F., Masanet E. (2016) Energy and emissions analysis of next generation electrochromic devices. Solar Energy Materials & Solar Cells 156 (2016)170–18