Journal of Solar Energy Research 21 (2017) 48-53

Journal of Solar Energy Research (JSER)

Journal homepage: www.jser.ut.ac.ir

The Effect of Neighborhood Shading on Building's Energy Performance, Case Study: Isfahan

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ARTICLE INFO

Received: 25 October 2016
Received in revised form:
5 February 2017
Accepted: 8 February 2017

Keywords:
Sun Shading; Urban regulations; Building's energy efficiency; setback line angles

A B S T R A C T

The sun position during building heating and cooling annual period has a major influence on the energy efficiency performance and must be adequately taken into consideration in the design process. Recently, in big cities the design and construction of energy efficient buildings has become a priority. This goal can be accomplished if natural resources such as solar radiation are wisely exploited. The real challenge, is to find clever compromises between urban and building design. For example, one of the major issues that causes trouble for people living in residential districts is insufficient solar gain and natural lighting of building interiors. Shadings caused by neighborhoods induces improper lighting condition and high energy consumption. These shadings can be caused by buildings, placed in opposite side of alley, although the design is performed in accordance with urban regulations. Shading could have positive effect on building's energy efficiency in summer, while its impact is disastrous in winter. Sun path drawings show that the shading effect of opposite side buildings is not considerable in summer, due to high solar altitude angles in Iran's central cities. In this study, after defining buildings typology, construction materials and window to wall ratios in Isfahan City, simulations are conducted with the aid of Energy Plus software, to investigate the influence of different parameters, such as opposite building's height on energy performance (annual heating and cooling loads). Daysim software was also used to compare daylight factor in sample model. The results show that urban codes, where the solar latitude during the heating and cooling period is not taken into consideration, should be optimized in regard to width of alleys and buildings' heights. As a result, modification of related urban codes must be proposed and setback lines should be optimized to reach more efficient and lively habitats.

1. Introduction

The development of cities with lack of necessary infrastructures and adequate regulations have caused important environmental problems. By 2050, nearly 70 percent of humans will live in cities [1], and 80% of greenhouse gases will be emitted from these areas [2]. Buildings in a city have a great impact on energy consumption and the resulting pollution. According to the International energy agency (IEA), residential buildings consume 30% of electricity, 40% of natural gases and 27% of total final energy consumption in 2013 [3]. Decreasing the amount of energy use in building sector, leads to a reduction of environmental pollution and CO_2 emissions. In UK and France, the target is set for all newly built homes to be zero carbon [4]. In USA, from 2000, Energy Star certification has been developed to rate and improve buildings energy efficiency and performance [5]. To overcome environmental concerns it is imperative to use renewable energy resources such as solar energy.

In recent decades, Iranian building regulations and city codes have reshaped buildings and cities. In this transformation process, the influence of the solar radiation, depending on climate and latitude of cities, is not taken adequately into consideration. The only mandatory measures for improving energy efficiency in new buildings are introduced in the national building regulation (19^{th} section). No compulsory action is defined for existing buildings [6].

Today in dense areas of cities, there is a tendency in constructing high rise residential buildings, without appropriate attention to energy and lighting issues. Despite all advantages of high rise buildings, the decrease of direct and diffuse solar radiation on transparent and translucent surfaces of the building envelope can have serious consequences on solar gain and natural lighting conditions, and the use of photovoltaic system can become completely unjustified.

Architect responsibility for improving life quality in buildings involves him in environmental aspects of the building design. Designing facades in harmony with the climate and the sun path (in cold and warm periods), by limiting or amplifying the incoming solar radiation can lead to minimizing heating and cooling load and maximizing natural lighting. The prevalent method to control sunlight in almost all of the buildings, has often occurred through overhangs and fins. In urban areas because of unlimited variables, sunlight control is more complicated. Shadings, caused by neighborhood blocks in dense areas of cities, could have great effects on buildings' thermal comfort conditions. In winter, shadings on account of sunray prevention from entering, decrease the number of buildings' heat gain hours.

High rise buildings and expanding living spaces in height in early twentieth had reduced lighting of urban spaces and consequently living areas. Since first decades of 20th century limitations have been imposed on building's height. These limitations often have been in relation to altitude angles and direct sun rays. These limitations don't have meaningful systematic impact on building's energy consumption. In consequence, an optimization process has to be performed to minimize building's heating/cooling loads with maximum exploitation of natural lighting.

In this research, after comparing the effect of neighborhood shading on heating and cooling loads and lighting conditions, for different widths of alleys, appropriate building's height and setback line angles are introduced.

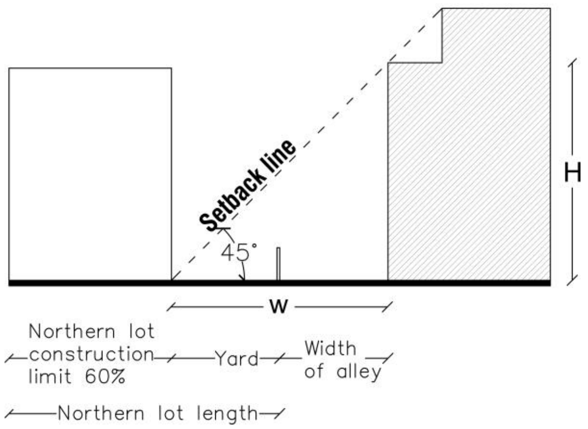
2. Building's height limitations

The position of sun and building orientations influence on the amount of sunrays entering the space. Sun's location is defined by azimuth and altitude angles which are assigned, in regard to location's latitude, for each time of the year. The differences in sunray angles result diverse shading's length in urban districts. In traditional introspective houses in Iran's hot and dry climate, all the functions around a courtyard had formed the house and residential zones placed in northern and southern side of the yard. In winter, due to the need for solar heat gain, inhabitants used to settle in northern part of the courtyard, while in summer, to avoid unwanted solar radiation, inhabitants used to live in southern part of the yard. In these houses kitchen and services were placed in western and eastern side of the courtyard [7]. Another method to control sunrays in traditional architecture was deep porches and shadings formed in terms of windows [8]. It is obvious that in new buildings, it is not possible to keep this traditional approach.

To control the effect of shading in cities, various types of regulations have been approved by many civilizations. Greeks and Romans had mandated minimum lighting standards for their cities [9]. In the United States, there was no low until in early 1900s daylighting problems in cities were revealed. In a primary research, in 1912, done by an architect named William Atkinson, the building's height was limited to 1.25 times the width of street and higher buildings were allowable (conceivable) only if setback lines were respected [10]. In New York's 1916 building's height law, the heights of buildings were limited to street width, and taller buildings should have been constructed according to defined setback line [11]. In the 1960s, most cities in United States were based on the floor area ratio (FAR) regulations. FAR is a quantitative measure which shows the number of times overall lot area can be multiplied and consequently determines the total allowable floor area of a building [12]. In Japan, urban regulations restrict building's height based on street's width and the height of neighborhood buildings, in order to supply enough space for daylighting and ventilation. In Japanese big cities, the maximum floor-area ratio of a building site, which has a road in front less than 12m wide, shall not exceed the value obtained by multiplying the width of the road in meters by a certain ratio [13].

One of the most important factors affect urban areas micro climate is the ratio between Height of buildings to Width of the distance between (H/W). Low values of H/W increase the sky view factor and are good for daylighting. Mills carried out a research on the relation between solar intercept factor and sky view factor for different building shapes with same total volumes. In this study it was concluded that for 30°N latitude, sunlight must be limited during the summer but perhaps not so during the winter [14]. In Van der Ryn and Calthorpe research on building's solar access, it was stated that in mid-latitudes, to maximize density, while preserving solar access, building heights should be limited to 5-6 stories, while at high latitudes 2-3 stories and at low latitudes 6-8 stories limitation should be implemented [15]. Dekay & Brown defined minimum spacing angle of 50 degrees for buildings in 28-32 N° latitude to have 85% lighting during the year between 9AM to 5PM [16].

In cities of Iran, such as Isfahan the FAR base regulations have been developed. According to approved urban regulations of Isfahan, shading space is defined as an imaginary space, which is determined by 45 degree setback line across south, starting from allowable construction limit of lot "Figure 1". On the other hand, the height of a neighborhood placed in southern side of the building should not exceed 40% of the northern part of property, when there is no alley between them. [17].



H = Allowable height without setback
W = 40% of northern lot length + width of alley
H/W = 1

Figure 1. Approved regulations of building's height in Isfahan

3. Simulation

To obtain optimum setback line angle, a study based on numerical simulation is performed, due to the fact that finding buildings in similar conditions with same neighborhood shading in urban areas is impossible. Furthermore, optimizing neighborhood building height, in regard to energy consumption depends on multitude of variables and needs parametric approach.

As seen in "Figure 2", sample building was modeled in a 200 m^2 lot with 20m $\times$10m dimensions. Allowable length to construct is equal to 12m. Each floor is considered as one thermal zone with the height of 2.9m.

Initially, to investigate the accuracy of existing regulations, the shadings of neighborhood in different hours for a sample day in winter (21 Dec), "Figure 3" and a day in summer (21 Jun), "Figure 4" were drawn for one case in regard to altitude angles in Isfahan. These angles were extracted from Weather Tools software based on Energy Plus weather file data. The neighborhood building height is calculated according to Isfahan height regulations and is taken equal to:

$$\text{Neighborhood building's height} = 40\%\ \text{northern lot} + \text{width of the alley} \quad (1)$$

In sun rays model "Figure 3 & 4":

Width of alley = 10m
The length of northern lot = 20m

Then,
Building height = 10m + 40% $\times$ 20m = 18m

In sample cold day due to low altitude angles the floors which are placed closer to ground receive less solar radiation and the first floor doesn't receive any direct illumination throughout the whole day. The second floor receives direct sunrays less than 3 hours and third floor gain is less than 4 hours. In summer, because of high altitude angles, there is no shading in first floor until 4 P.M and in second floor the shading occurs after 5 P.M. It can be concluded from these figures that the height of neighborhood building should be optimized based on sunlight and solar heat gain.

In this research, to obtain the optimized setback line angle, annual energy consumption for lighting and heating/ cooling is simulated. Lighting is simulated with Daysim software. The model has an installed electric lighting power of 1200W. It is manually controlled with an on/off switch. The dimming system has an ideally commissioned photo sensor-control with a ballast loss factor of 20 percent. Heating/cooling loads are simulated with Energyplus and Honeybee plugin for grasshopper, which makes parametric simulations possible. In the models, cooling set point is assigned to 27 C° and heating set point is 21 C°.

The height of neighborhood building, base building's height and the width of alley are assumed as variables. The height of neighborhood building is simulated from 3 to 32 m (30 cases) in each width of alley. Alley widths are taken equal to 10, 14, 18 & 22m. Main building height is considered 3, 4 & 5 floors. Overall number of simulated scenarios is equal to 360.

Variable number of floors are chosen, because when total energy consumptions of all zones are calculated then the impact of shading on low rise apartments' annual energy consumption could be more. For all of 360 scenarios, which are simulated, in each case the annual energy consumption is obtained. Minimum and optimized heights for each width and number of floors are determined, according to total energy consumption. Afterwards, 12 setback line angles are defined.

4. Setback line angles

Annual total energy in diverse case are obtained by sum of the heating/cooling and lighting energy in kWh/m^2. In each case, minimum annual energy based on height is simulated and the diagrams are drawn.

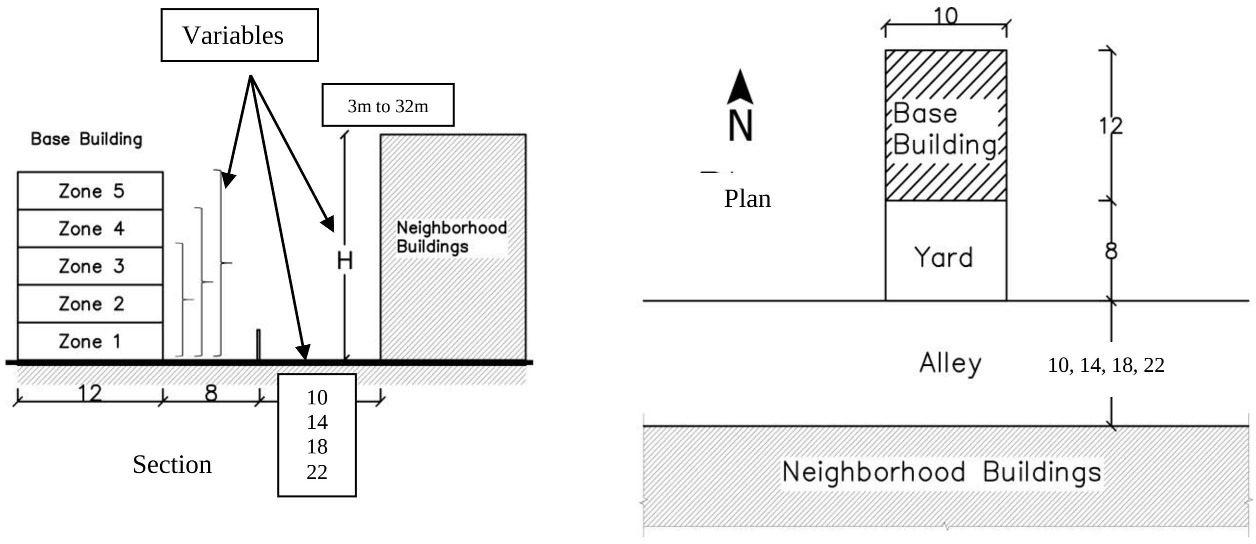


Figure 2. Sample model and variables in simulation

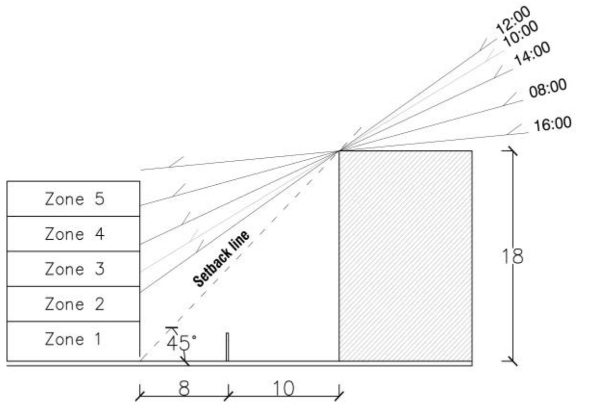


Figure3. Shading of neighborhood building in 21 Dec, based on 45° setback line angle, as an approved regulation.

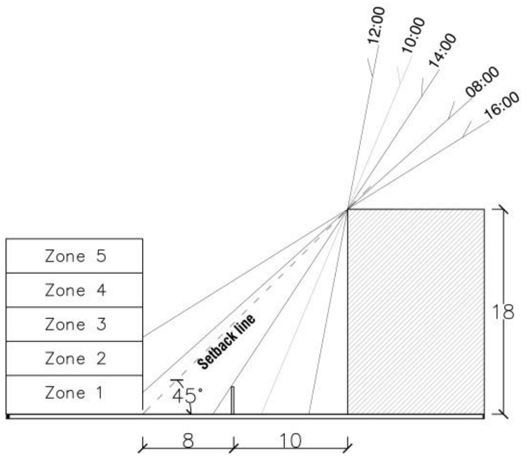


Figure 4. Shading of neighborhood building in 21 Jun, based on 45° setback line angle, as an approved regulation**.**

In "Figure 5" annual energy consumption for 4 floors building (4 zones) is shown with diverse widths of alleys. In this model, minimum energy consumption is 156.05 kWh/m^2 for 10m width of alley, 155.97 kWh/m^2 for 14m, 156.05 kWh/m^2 for 18m and 155.93 kWh/m^2 for 22m. Minimum Energy consumption values occur for lower neighborhood heights, and with the increase of neighborhood's height, main building's energy consumption begins to increase after a critical value depending on the width of the alley, with a relatively constant rate. Before reaching the maximum value, the slope of the curve decreases progressively. The increase of energy consumption for higher height values put into evidence the predominating influence of the cold period on annual energy consumption. In other words, shading of neighborhood building has more effect on energy consumption in cold winter days, in comparison with the situation in hot summer days, when this shading helps to decrease cooling energy. For fixed values of neighborhood height, the increase of width of alley leads to the decrease of the annual energy consumption. According to Isfahan's approved regulations for building's height, in this model, the neighborhood's height is taken equal to 40% length of lot + width of alley, for 45° setback angle. According to this calculation rule, four set of values are selected for the projected study and comparisons. These sets of

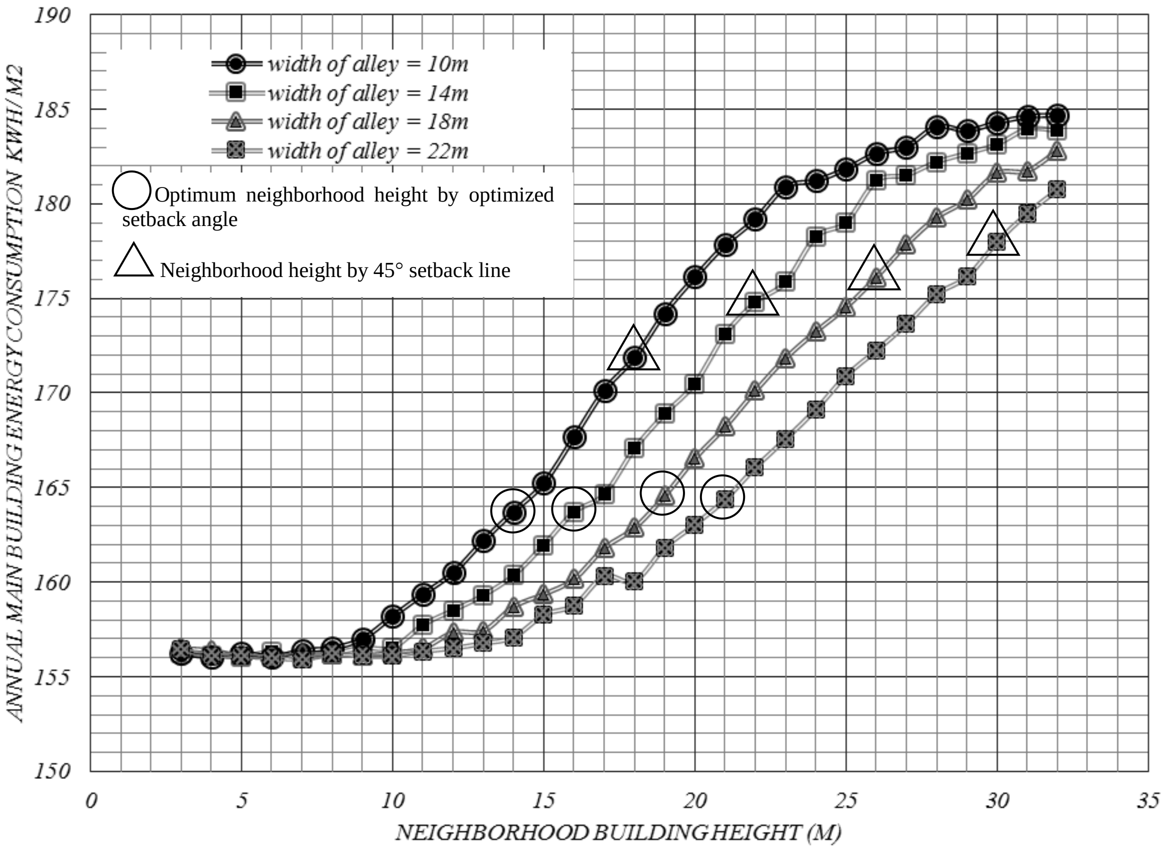


Figure5. Different cases annual energy consumption in 4 floors model and Comparing 45° setback line and optimum set back angle annual energy consumption

values are as follows in "Table 1":

Table 1. Neighborhood's heights, based on sample model's length and width of alley in regard to 45° setback line

width of alley (m)	neighborhood's height (m) (45° setback line angle)
10	18
14	22
18	26
22	30

Energy consumption in each case and other heights (from 3m to 32m) are shown in "Figure 5". The diagram shows that in all cases the neighborhood heights which are obtained, based on approved regulations in Isfahan, are closer to maximum energy consumption, rather than minimum calculated values. It should be noted that the neighborhood height in which minimum energy consumption occurs cannot be chosen as the “best” solution, because it leads to low neighborhood heights and is not compatible with the minimum acceptable density of urban area. As a result, to get closer to more “applicable” values for setback line angles, the optimum heights which are 95% close to minimum energy consumption are obtained in each case and corresponding setback angles are calculated. In "Table 2" different alley's widths with diverse number of floors for main building have been listed. In each case, the percentage of annual energy demand reduction for optimum height, in comparison with 45° setback line angle case, is calculated. Optimum setback line angles are between 31 to 40 degrees. In different widths of alleys, in diverse number of base building's floor, setback line angles are closer to each other. In a four-storey model, setback line angle is 38° for 10m alley while it is 35° for 22m width of alley.

Optimum setback line angles are between 31 to 40 degrees. In 3storey building, optimum setback line angle in which neighborhood building's height should be determined varies between 31 to 36 degrees. In 4storey building, optimum setback line angle is between 35 to 38 degrees and in 5storey building, this amount varies between 35 to 40 degrees.

As the width of alley increases, optimum setback line angle is decreasing. For example in 4 floors building which has a 10meters-wide alley in front, neighborhood building could be built by 38 degrees setback line angle while in a 22m alley neighborhood building should be built by 35 degrees setback line.

5. Discussions

In this research the variation of annual energy consumption for 3, 4 and 5storey buildings in regard to the height of neighborhood buildings have been investigated. Although the decrease of energy demand, due to optimum setback line angles are not significant, in comparison with 45° setback line case (approved by the regulation), in larger scale (urban area or a country), this can lead to a high amount of energy saving.

Optimum setback line angle is based on proximity to minimum energy consumption, but it shouldn't be exactly as same as setback line angle in which minimum energy consumption happens, due to minimum density limitations. With 95% nearness to minimum energy consumption, more feasible solutions, in accordance with the minimum permissible density of urban areas can be obtained.

To avoid the effect of other influencing parameters on energy consumption and eschew probable errors, the rates of infiltration, ventilation, and equipment usage have been supposed to be at a minimum level. This is one of the major reasons why the calculated amount of energy consumptions (per square meter) is sensibly lower than roughly estimated values of energy demand of buildings of Isfahan.

Results are in range, which is defined by Mills (26° to 45° setback line angles in 30°N latitude) [14]. The differences in results leads in the fact that in our research, both energy consumption and lighting have been determined, and as a result, the range is more limited (from 31 to 40 degrees).

Dekay & Brown define optimum setback line angles in low density districts in 32° latitude (same as Isfahan's latitude) about 50° [16]. This probably have occurred because Dekay & Brown definition is only about daylight factor and they didn't consider energy consumption.

These angles could be used as a base to improve urban regulations in Isfahan and cities located near 32° latitude, but it's imperative to consider cultural and economic constraints in addition to density in each urban district.

6. Conclusions

Solar energy has an important role on residential building's lighting and energy consumption. Approved regulations for building's height in urban districts could be effective in the building's availability to sun and sky view. Neighborhood buildings which are constructed in front of a building in southern side, affect building's solar gain and lighting. In addition to neighborhood's height, the width of alley could have impact on annual energy consumption. It should be noted that the number of building's floors changes the amount of energy demand per area. As the number of storey of the main building increases, the percentage of energy demand per area decreases, due to the decrease of neighborhood building shading’s influence. Therefore, in high rise apartments, the effect of front neighborhood's shading on annual energy consumption decrease.

Width of alley is one major factor in determining the amount of front neighborhood's height. When the width of alley increases, it is possible to have lower setback line angles, because in lower width alleys the overall height of neighborhood is less and to provide enough density it is not possible to reduce setback line angle.

Optimum setback line angles for Isfahan, obtained in this research, are between 31 to 40 degrees, depending on the width of alley and number of main building's floor. Energy demand obtained by optimum setback line angles, in comparison to the case in accordance with the approved regulation, which is defining 45 degrees as setback line angle, decreases as the setback line angle is reduced. In defining setback line angles, it is imperative to consider density in urban districts. However, when the angles of setback lines decrease, more efficiency is provided but also it creates limitations on density. One possible solutions to improve this problem is, to construct building stepped with setback and avoid high rise buildings in residential zones.

Table 2. Optimum setback line angles and their comparison to 45° setback angle approved by the regulation

Number of base building floors	Width of Alley (m)	Neighborhood building setback angles and energy consumption					
		Optimum setback line angle (°)	Minimum setback line angle energy consumption (kWh/ m^2)	Optimum setback line angle energy consumption (kWh/ m^2)	45° setback line energy consumption (kWh/ m^2)	%nearness of Optimum angle energy consumption to Minimum angle energy consumption	%Energy demand reduction in comparison to 45° setback line angle
3 floors	10	36°	117.33	123.92	132.99	95%	7%
	14	32°	117.204	123.81	135.73	95%	10%
	18	33°	117.39	124.54	136.58	95%	10%
	22	31°	117.387	123.39	137.23	95%	12%
4 floors	10	38°	156.05	163.73	171.87	95%	5%
	14	36°	155.97	163.71	174.79	95%	7%
	18	36°	156.05	164.55	176.11	95%	7%
	22	35°	155.93	164.37	177.96	95%	8%
5 floors	10	40°	194.20	202.48	209.77	95%	3%
	14	39°	194.13	204.20	212.79	95%	4%
	18	38°	194.14	203.78	215.31	95%	6%
	22	35°	194.11	204.41	219.23	95%	7%

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