350: New Zealand Daylight Code Compliance Tool: Development and Implementation

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Abstract

The New Zealand Building Code specifies a minimum requirement for natural light in all habitable spaces within dwellings. In the absence of a simple to use verification procedure, this minimum requirement is not being met in a number of apartment buildings, with up to 62% of the current apartments failing to meet this requirement post-construction.

The aim of this research project was to develop a tool that is simple and easy to use, reasonably accurate and could be easily implemented to address the issue of daylight compliance in New Zealand apartments.

This paper describes the processes involved in developing a compliance assessment tool for the building code. The tool will identify when apartment buildings require simulation to prove compliance. This paper includes a description of: the simulation and analysis of variables affecting daylight levels in apartments, producing an assessment tool; the calibration process used to determine if the tool provides accurate results; and the critique of the usability of the tool.

Keywords: Daylight, Apartment Buildings, Daylight Regulation, Daylight Simulation

1. Introduction

The natural light minimum specified in the New Zealand Building Code (NZBC) for all housing is an illuminance in all habitable spaces of no less than 30 lux at floor level for 75% of the Standard Year [1]. This is not difficult for typical New Zealand houses to achieve. However, this requirement is not always being met in the medium rise apartments that are becoming more common in New Zealand urban areas [2]. A number of factors relating to availability of natural light need to be considered when designing apartment buildings that differ from those relevant to designing houses.

The aim of this research project was to develop a tool that is simple and easy to use, reasonably accurate and could be easily implemented to address the building code issue of compliance with the natural light requirements in apartments. A feasibility study was conducted prior to the commencement of this project determining that it would be possible to develop a tool to meet the above criteria [3].

The compliance tool has been developed through the simulation of various environmental and building conditions that affect daylight levels in apartments. The conditions simulated represent the typical range found in New Zealand cities and apartment buildings. The tool considers eight main variables for the building conditions and surrounding environment including Street Width, Opposite Building Height and Glazed Area, and the interaction between these variables.

The principal intended use of the tool is the calculation of the level of risk of non-compliance with the NZBC minimum light level. It is envisaged that if the tool suggested there is a risk of non-compliance, then a full simulation would be required.

Calibration tests were conducted to ensure that the tool provides the correct results for real situations, with daylight factor measurements in a range of apartments compared to the compliance tool ‘prediction’ in 3 major cities: Auckland (latitude 36.8S), Wellington (latitude 41.2S) and Christchurch (latitude 43.5S).

This paper outlines: the background of this research; the research method used for the development, calibration and critique of the tool; the results for each section; and gives examples to show how the tool would be used in practice.

2. Background

2.1 New Zealand Context

Over the past 10-15 years an increasing number of apartment buildings have been built in New Zealand’s main urban centres; Auckland and Wellington in particular. As with many other cities internationally, this can be attributed to: an increased demand for inner-city living, as a result of decreased commute time, a more vibrant street life, increased demand for local retail services and denser local labour market for office staff; and local governments’ efforts to limit urban sprawl [2].

With these inner-city developments come a number of factors reducing the availability of natural light that were not envisaged at the time of implementing the code for natural light. These major factors include: proximity to surrounding building(s), height of obstructions and apartment layout/design [4,5,6,7,8]. The difference in these factors between detached housing and inner-city apartments can be sizable: with some street widths in urban areas being as narrow as 5-8 metres; obstruction heights show increases from around 6 metres in suburban areas to up to 90-95 meters maximum height in Wellington CBD [9].

2.2 NZBC G7- Natural Light requirement

The NZBC natural light requirement is a performance based regulation that is a requirement for all new housing built in New Zealand. The code specifies that a minimum of 30 lux is needed at floor level for 75% of the standard year (between 8am and 5pm) [1]. Currently, the primary method of assessing compliance is based on the glazed area of 10% of the floor area, the same value used in a number of other daylight regulations and standards internationally [10,11].

Within the code compliance documents, it is stated that '10% window area to floor area equates to approximately 33 lux at floor level for 75% of the standard year,' however research has shown that this value whilst relevant to suburban detached housing is not relevant for apartment buildings [12].

This research is intended to develop a tool that can be included in this code as the primary method of compliance assessment for all new for apartments.

2.3 Pilot Study

A pilot study [3,13] was conducted in 2006 to determine if it would be possible to develop a tool to assess whether apartments would comply or whether proof of compliance would need to be provided with the building consent application. In the pilot study, it was determined that such a tool could be created by developing a preliminary tool for typical situations found in Wellington. However, the tool developed in the pilot study required a lot of modification and testing before it could be implemented.

This research built on that of the pilot study through: a larger range of variations, with over 10 times the original data; a more robust mathematical basis was used in the development of the tool; a more extensive calibration process was undertaken; and end-users were involved in the development process.

3. Research Method

3.1 Overall Method

The process used for this research followed a standard process for preparing a tool for implementation, documented by Professor Edward Ng in his articles on the development of a daylighting design tool for high-density residential buildings [7,8] in Hong Kong and confirmed during a 1 month period working there.

The research comprised three main sections: Development, Calibration and Critique of the tool.

The development of the tool involved simulation of urban environmental variables that affect daylight in interior spaces. The simulation data was analysed to develop a prediction model for the percent of the year that 30 lux is exceeded. This criterion formed the basis of the tool – comparing the percent of the year with the 75% guidance in the NZBC code compliance documents.

Once the tool was created, its results were calibrated against measurements taken in a selection of apartments to determine accuracy. The tool was also critiqued by potential end-users to evaluate its usability and functionality.

Throughout the research, three criteria were used as a means of assessing the success of the research. These criteria were that the tool was to be: simple and easy to use; reasonably accurate and easily implemented. These criteria are adaptations of the criteria Ng used in the development of his daylighting design tool [8].

3.2 Development of Tool

A literature survey was conducted to determine the variables that would be tested in the simulations and calculated in the tool. The variables were: apartment type (floor area and shape); street width; opposite building height (mean building height above sea level); orientation; glazed area; daylight availability and angles (location); reflectance of opposite building; ceiling heights; proposed building height; glazing transmittance; and vertical location of lowest apartment within the building. Other factors identified but not included were: interior surface reflectance; apartment dimensions, window location (including head and sill heights) and building form (including atrium and light-wells).

The main reasons for not including these factors were that it is often difficult to know this information at the early design stage when it is expected this tool may be applied and there is often little variation between different apartments. Where possible, industry standards were used as the basis for these assumptions: for example, the New Zealand Standard for interior lighting (AS/NZS 1680.1:2006) values were used to specify typical internal surface reflectances of 0.8 (Light Ceiling), 0.7 (Light Walls) and 0.25 (Medium-Dark Floor).

A base model was produced which was modified for each variation. This base model was built using the mid-point and/or most common variation of each variable.

A total of 520 variations were tested. Simulations were produced using the daylight simulation program DAYSIM [15], which provided assessment of the annual daylight profile of the apartments and gave a percent of the year that 30 lux is exceeded.

The output from DAYSIM was assessed using SPSS [16] to establish the effect each variable had on the illuminance inside a typical apartment. The aim of the analysis was to produce a prediction model that, based on the conditions of each variable, would specify the percent of the year that 30 lux will be achieved in the lowest performing apartment in a building. A prediction model is a multiple regression calculation where 'the goal is to forecast an outcome based on data that was collected earlier' [17].

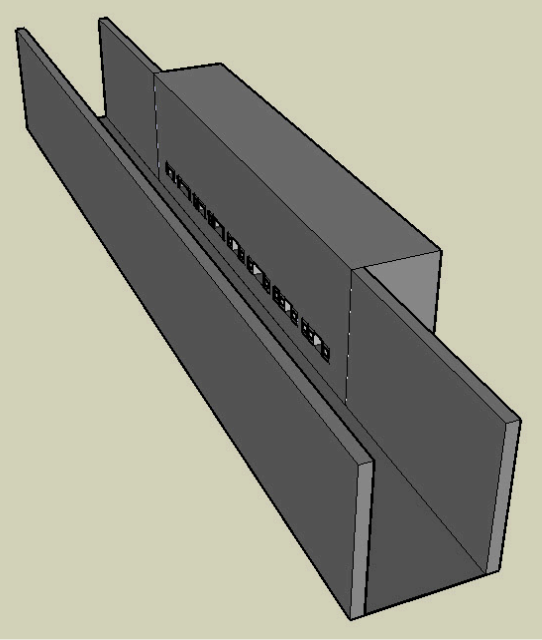


Figure 1. Simulation Base Model

3.3 Calibration of Tool

The calibration (or 'design tests') of the tool was conducted to ensure it provided reasonably accurate results. The process used for the testing of the tool involved the measurement of at least 80 apartments which were considered to be representative of the range that would be found in New Zealand. This process was adapted from Professor Ng's [15] research in the development and implementation of a tool for Hong Kong building regulations.

Based on the 'rule of thumb' [18] for minimum sample size of ten times the number of variables, 80 apartments were considered to be the minimum number of apartments to check the accuracy of the tool.

The method of conducting measurements in the apartments was to take illuminance measurement in the back two corners and in the middle at the back of each habitable space. The measurements were taken at floor level, 0.6m from the walls, which is considered to be the lowest point of illumination [19].

At the same time, illuminance levels were recorded outside under an unobstructed overcast sky. Using the internal and external illuminance values the daylight factor [20] at each measurement point was calculated. From the daylight factor value, the illuminance exceeded at each point for 75% of the standard year can be calculated using the skylight availability values given in the Australian and New Zealand interior and workplace lighting standard [21].

The illuminance values at each point inside were then compared to the building code requirement of 30 lux to determine if they comply or not.

The compliance assessment tool was applied to each of the apartments measured to determine if the tool accurately assessed each situation.

3.4 Critique of Tool

To ensure that the tool was suitable for the end-users, an evaluation was undertaken. Potential end-users were invited to participate in an evaluation of the tool. The group comprised of: representatives from the Department of Building and Housing; representatives from Territorial Authorities that have major apartment development in their region; and architecture/engineering firms that are known to design apartment buildings.

Each participant was asked to test out the tool over the period of one week, and at the end of that week, answer a questionnaire. The focus of the questionnaire was to test the usability and gain feedback on aspects that need improvement.

The feedback from the questionnaire was analysed and changes to the tool were made where appropriate.

4. Results

4.1 Development of Tool

520 simulations were conducted, looking at the effect that 11 variables, and the interaction between these variables, had on the illuminance levels inside an apartment. Multiple regression analysis was performed for each variable and a combination of variables. The following equation shows the effect that the height of the opposite building(s) has on the **D**aylight **A**utonomy value (the percent of the year that 30 lux is exceeded at the selected measurement point), figure 6 shows the graph of this relationship:

$$DA = 78.231 \times 0.956^{BH}$$

As a result of the regression analysis, it was found that apartment type, proposed building height and ceiling height did not have strong statistical relationships and were therefore omitted from further development of the tool. Although these factors would most likely have had a small influence on the outcome, this would have severely compromised the accuracy of the tool.

Using the regression analysis for each of the variables and interactions, a final, complex formula was produced.

The calculation was then formatted as an Excel spreadsheet to allow a complex calculation to be used without the user needing to perform any calculations, removing the possibility for user errors. The tool is shown in figures 2 and 4.

4.2 Calibration of Tool

A total of 97 apartments were measured, 5 in Auckland, 4 in Christchurch and 88 in Wellington. The 88 in Wellington were representative of the range typically found in New Zealand and exhibited the various combinations of variables the tool would be required to accurately assess. The apartments in Auckland and Christchurch were selected to assess the latitude dependence of the data.

Daylight factor measurements were determined and were then used to calculate the illuminance that is exceeded in the apartments for 75% of the standard year.

The compliance assessment tool was applied to the 97 cases to determine if they should have been simulated to prove compliance with the minimum code requirement.

The calibration process found that 62% of the apartments failed to meet the minimum requirement. From the measurements taken in the apartments, it was found that 46 out of 97 rooms exceeded the minimum requirement and 35 failed to meet the requirement, 16 rooms were considered to be borderline (within 5 lux of the minimum requirement).

To ensure assumptions like internal reflectance values were fair, a quick survey was conducted on these aspects for each apartment, it was found that 96 of the 97 rooms had white ceilings, 80 out of 97 had light coloured walls, and floors were typically medium to dark carpet with 68 out of 97 having medium coloured carpet and 29 out of 97 had dark coloured carpet. This confirmed that the use of the industry standard values were representative of the majority of situations.

The correct result was provided by the tool for 85% of the cases, of the 15% of the incorrect results, 10% would have required simulations as a result of another room that had been measured within the building failing to meet the minimum requirement. This issue typically arose where apartments were measured on higher floors (6th floor or above) that passed, but apartments on the lower floors of the building failed. This highlighted that clear limits need to be placed on the application of the tool.

The calibration exercise shows the tool provides the correct result for the majority of cases. It is reasonably accurate. Specifically: of the 97 situations, just three were given incorrect outcomes that were not justified because other apartments within the building still failed. Of these three situations, two were borderline apartments where the tool gave a pass result but measurements found the apartment did not meet the minimum requirement. It should be noted that if these two apartments did not have furniture when measured then it was likely they would have passed. Our conclusion is approximately 1 in 100 cases might require simulations when they were not necessarily needed and all buildings that need simulations would be correctly identified.

4.3 Critique of Tool

The results from the participants that were invited to critique the tool provided an insight into what potential users think of the tool and its functionality. Most participants found the tool to be about right in terms of complexity and time involved in applying the tool. However, it is noted that there may be some reluctance to the implementation of a more complex method of regulation than is currently in place.

5. Example

5.1 Cases

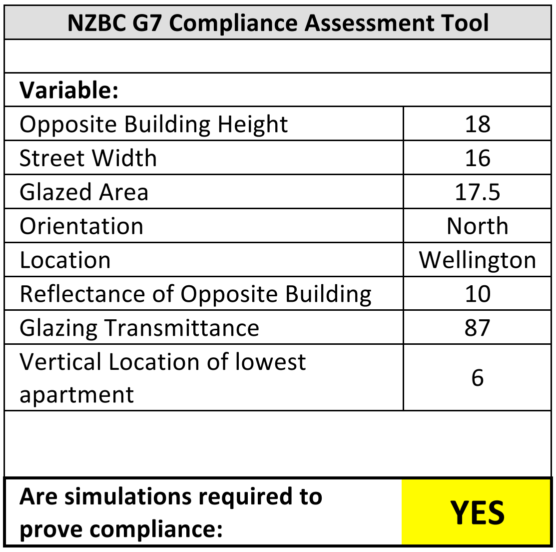
These examples show how the tool would be applied using two of the calibration apartments. The apartments are situated in the area of Wellington City that has the most apartment buildings. They are considered to display the typical features found in many of New Zealand's mid-range apartment developments. The selected cases are two borderline apartments, one compliant and one non-compliant.

5.2 Application of tool

The tool was used to assess the example apartments. The appropriate information was entered in each cell and an output was provided to specify if the apartments would need simulations provided to prove compliance with the building code or not, where an answer of 'YES' indicated that the building will most likely not comply with the building code and 'NO' the building will definitely comply.

5.3 Case 1

The application of the tool for the first case is shown below in figure 2.



NZBC G7 Compliance Assessment Tool	
Variable:	
Opposite Building Height	18
Street Width	16
Glazed Area	17.5
Orientation	North
Location	Wellington
Reflectance of Opposite Building	10
Glazing Transmittance	87
Vertical Location of lowest apartment	6
Are simulations required to prove compliance:	**YES**

Figure 2. Application of the tool for the example apartment.

As can be seen in figure 2, the tool has indicated that this apartment is likely to be non-compliant and should therefore conduct simulations to prove compliance with the minimum requirement.

5.4 Result

The result was compared to actual measurements taken in this apartment. Figure 3 shows the estimated percent of the year that 30 lux is exceeded in the back two corners, based on daylight factor measurements.

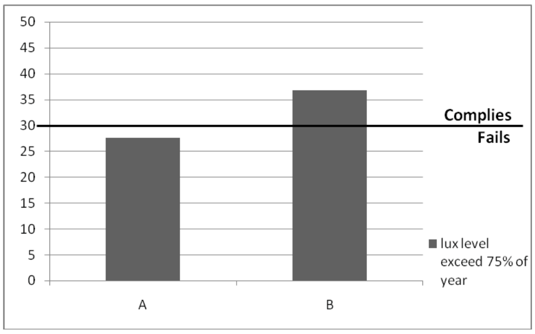
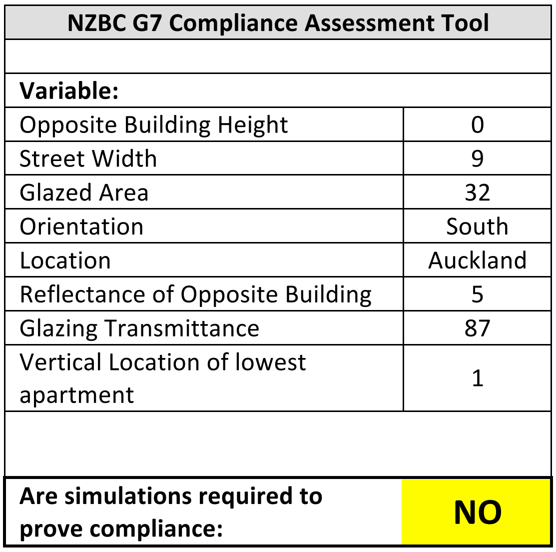


Figure 3. Lux level as calculated from measurement in example apartment.

From figure 3, it can be seen that the example apartment fails to meet the minimum code requirement post-construction, and should therefore have had simulations done to prove compliance in the design/consent stage. This confirms the tool provided the correct result for this case.

5.5 Case 2

The application of the tool for the first case is shown below in figure 7.



NZBC G7 Compliance Assessment Tool	
Variable:	
Opposite Building Height	0
Street Width	9
Glazed Area	32
Orientation	South
Location	Auckland
Reflectance of Opposite Building	5
Glazing Transmittance	87
Vertical Location of lowest apartment	1
Are simulations required to prove compliance:	**NO**

Figure 4. Application of the tool for the example apartment.

As can be seen in the figure 4, the tool has indicated that this apartment is likely to be compliant and therefore would not require simulations to prove compliance with the minimum requirement.

5.6 Result

The result was compared to those taken in the apartment. Figure 5 shows the estimated percent of the year that 30 lux is exceed in the back two corners (point A and C) and in the centre at the back (point B), based on daylight factor measurements.

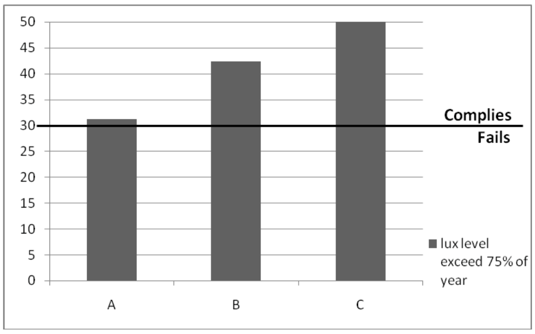


Figure 5. Lux level as calculated from measurement in example apartment.

From figure 5, it can be seen that the example apartment exceeds the minimum code requirement post-construction, and it would not have been essential that simulations were conducted to prove compliance in the design/consent stage. This confirms that the tool provided the correct result for this case.

6. Conclusion

The aim of this research was to develop a compliance assessment tool that can be added to the New Zealand Building Code natural light clause on completion of this research. The three criteria used to ensure the success of this research were that it was to be: simple and easy to use; reasonably accurate; and easily implemented.

The first criterion was fulfilled through the application method of the tool and the critique provided by end users. The use of an excel spreadsheet to perform the calculation, where the user is not required to undertake complex calculations, resulted in a format that was simple and easy to use. A critique of the tool by potential end-users of the tool meant that they were able to provide valuable feedback and suggestions on ease and simplicity of use, allowing the tool to be altered prior to implementation.

The second criterion, that the tool was to reasonably accurate, was assessed through the calibration process. Testing the tool against real apartment situations meant that the reliability of the tool could be assessed in a number of different real situations. It was concluded that the results provided by the tool were reasonably accurate, with 85% of the cases having the correct outcome.

The third criterion, that the tool was to be easily implemented, was more difficult to assess. A tool has been developed that is ready for implementation, but as with any regulations, it may take time before this tool is included in the building code. Although, it is felt that through a combination of a strong method used in the development of the tool, proven accuracy of the tool and a critique by end-users, that implementation of this tool is feasible.

In conclusion, the original aim of this research has been fulfilled. A compliance assessment tool has been developed for the New Zealand building code natural light requirement in apartments that is simple and easy to use, is reasonably accurate and can be easily implemented. It is hoped that the tool will be added to the New Zealand Building Code Clause G7 Natural Light Compliance Documents as the primary method of compliance for apartment buildings in 2009.

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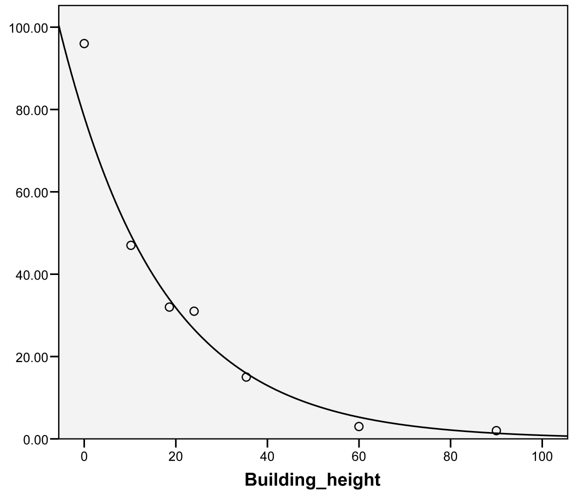

Figure 6. Regression Analysis graph for the relationship between building height and the percent of the year that 30 lux is exceeded.