

Commercial building façade design: the relationship between early design lessons and detailed design lessons

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ABSTRACT: This study uses high performance heavily glazed façades (developed by architects and engineers) for a real commercial building to examine the relationship between COMFEN's early design lessons (single-zone simulations) and the detailed design lessons (multi-zone simulations) derived from use of Energy Plus. The hypothesis tested is that the COMFEN-based decisions which are derived from computer simulation of single-zone performance 'sketches' of the proposed building are consistent with the multi-zone simulations in the full version of Energy Plus. The result of using COMFEN and Energy Plus often, but not always produces predictions of energy performance that are consistent across different scenarios. This analysis suggests that early design tools like COMFEN need to be used with care to ensure a design message that is consistent with the predictions of a detailed design model. At present they could potentially mislead architects during the early design stage.

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INTRODUCTION

Modern commercial buildings are often heavily glazed. This is often argued to have a huge impact on the energy consumption. Architects sometimes suggest these large areas of glazing in curtain walls, floor to floor ceiling windows or similar systems maximise daylight. This is argued to be a "Green" way to design. However, it often appears that this is more a particular building aesthetic. Proponents of high tech buildings argue that the poor performance is not an inherent property of the heavy use of glazing. The problem is argued to be the design team ignoring various important environmental factors. Increase of energy consumption/cost results from the requirement for heavy use of mechanical equipment to cope with overheating on sunny days, excessive heat loss on cold days, glare on sunny and even cloudy days because these interior comfort issues have not been systematically studied during the whole of the design process. To create a successful highly glazed building it is not enough to run computer simulation packages during the developed design and drawing documentation phases of a building project to determine how big the mechanical equipment needs to be. Rather, the design team must carefully simulate these comfort and performance issues from day one of the building project design process.

The Lawrence Berkeley National Laboratory (LBNL) computer program COMFEN (COMmercial FENestration) is an interface that makes the power of the complex simulation package Energy Plus available in the very early sketch stages of the design process. In the same manner that an architect will often use a high quality drawing tool to sketch, the high quality Energy Plus simulation tool can be used to sketch performance. The present study focuses on building façades, the design of which has a significant influence on building energy use and occupant wellbeing. Glazing height, materials, orientation, design conditions all play a significant part in the overall energy performance of a building. COMFEN, which focuses on the design of the façade of the building, is used as the analysis tool in this research.

Using COMFEN, façade designers during early design can simulate concept 'sketches' quickly because the complex simulation package of Energy Plus is available through this interface. The tool provides the designer with an ability to 'sketch' the performance of the façade. This is essential information to have during early design. COMFEN focuses on the façade design within a single-zone. Energy Plus without the COMFEN interface is typically used during detailed design to simulate an entire (multi-zone) building. This study examines the consistency of early design lessons and detailed design lessons derived from the parallel operation of COMFEN (early design process) and Energy Plus (detailed design process).

1. BACKGROUND

Many sources point out the negative effects of using large areas of glazing in buildings. For example, Lstiburek (2008:28) says:

“Do you want to save serious energy and serious money? That’s easy. Use less glass. Windows and curtain walls are the most expensive component in a building and provide the worst energy performance. The more you use, the more energy and money you burn. Limit the glazing area to approximately 30%, and use good glass and frames.”

And, Tzempelikos & Athienitis, (2005:227) state:

“There is just too much glass used on these curtain wall systems, all because of the aesthetic and this makes it very difficult to enclose conditioned air; the building relies on the mechanical systems to maintain comfort. Fenestration and shading systems have a major impact on visual and thermal comfort in perimeter spaces but also on energy consumption, peak loads, and possibly HVAC system sizing.”

The following Environmental Factors are generally agreed to have a large impact on a commercial building’s energy consumption, and to be governed by the amount of glass in a building façade:

- Building over-heating potential: More heat can transfer through the building façade if it’s heavily glazed. This means more HVAC energy consumption to achieve adequate comfort level for occupants.
- Heat loss of interior space: in a cooler climate such as Wellington’s winter, the ambient temperature is much lower compared to internal temperature. Buildings with large glazed façades make heat storage difficult during cold weather, so comfort is relied on mechanical heating.
- Glare from daylight/sunlight: Occupants enjoy having daylight in office spaces but often excessive/uncontrolled luminance can cause discomfort and disturb workers’ productivity. Controlled daylight increases occupants’ satisfaction.
- Glare from heavily glazed buildings: reflected light from glazed façades can affect neighbouring buildings, forcing occupants inside to draw blinds and switch on artificial lights, the end result is extra energy consumption/cost.

Hence, the inspiration for this study was this issue of ‘fully glazed façades’: However, the problem with the above list of problems is that it can become a recipe for reducing the amount of glass to unacceptably low levels. It is clear that no glass connecting the interior to the exterior is an undesirable outcome for most building occupants. It is less clear how much glass is too much. What designers need is a means of comparing design options for fenestrations systems: glazing systems plus shading systems plus external shades. Decisions made early in the design process – particularly of an aesthetic nature – often are locked in for the full duration of the design and construction of a building project. This requires a consistency in analysis tools all through the design decision phases for a building. This research focuses not on the exact magnitudes of the performance predictions of performance sketch and fully detailed design decision support tools. Rather, it compares the energy and environmental impact lessons from the performance sketch design analysis with those from the developed design analysis.

The design analyses must be accurate and consistent throughout the design process in order that each design team can examine for their site and design programme claims such as: “Many ‘Green’ buildings don’t save energy. Why? They have too much glass, they are over ventilated, they are leaky to air, they are fraught with thermal bridges and they rely on gimmicks and fads rather than physics.” (Lstiburek 2008:28).

The purpose of this study is to examine the consistency of the early design lessons from a performance sketch design decision support tool when compared to the lessons from a detailed analysis tool. If consistent, the impact of curtain walls can be analysed accurately during the early design process (COMFEN) and various façade designs can be tested quickly; allowing architects to reliably select the best façade option early. However if early design decision support tools are inconsistent with detailed design tools, this makes the prediction of façade performance difficult. Ultimately, if buildings are to have façades that function well, then architects and engineers must cover all the major issues during the early design process (overheating, heat loss, and glare).

The methodology adopted is to compare the outputs of COMFEN and Energy Plus. First, COMFEN is used to produce a ranking of building façades in terms of their thermal, lighting and environmental performance. These rankings are based upon the COMFEN performance sketch – a single-zone ‘building’ with a fenestration system on one wall. Then these façades are implemented in a full scale non-residential building model in Energy Plus. Performance of the façades is again ranked and then this new rank order is compared to the single-zone based ranking.

2. LITERATURE REVIEW

In a simulation approach there should be very few shortcuts or assumptions connecting general building design features and performance. Glazed façades are neither bad nor good; they are just a building feature to be modelled.

“The design of an intelligent, energy conscious building, which is environment-friendly, requires a careful analysis and evaluation of all proposed design alternatives throughout the different design stages. The aim in an energy

conscious building design is to minimize the required energy for heating, cooling and lighting, while relying as little as possible on energy from polluting fuels" (Shaviv 1999).

Instead of shortcuts and assumptions, a mathematical model is constructed to represent directly the heat flow paths and interactions observed in the reality. In this sense a simulation model is an emulation of the reality (Clarke & Maver 1991). Building design tools (Papamichael & Ellington 1994) help building designers understand the energy and cost impacts of changing the values of building parameters (such as shape, orientation, and number of floors).

"Building performance simulation has become an accepted method of assessment during the design process. With increasing complexity of building designs and higher performance requirements on sustainability, use of building simulation will become inevitable" (Hoes, Hensen, et. al. 2009).

Consistency between the early and detailed design tools has been argued as an essential part of this design process. So it's important to start from day one.

"...there are some buildings that are doomed from day one to perform poorly. In some cases this is because the basic design is poor, but the problem can also affect buildings that have apparently reasonable design and construction, at least at the macro level. In such cases, the buildings may simulate well, but real-life problems swamp the performance to the extent that the theoretical performance has little chance of ever being achieved" (Bannister 2009).

"Building façade design is developed at a very early stage of the design process. It is often the basis for the award of the contract to a particular firm of architects or developers." (Kolokotroni, Robinson-Gayle, Tanno, & Cripps 2004:3). They suggest one of the drivers for highly glazed façades is its popularity amongst clients. The system is perceived to enhance the building façade's appearance, to facilitate occupants' connection to outdoors (daylight). Architects are almost forced to design this way to secure projects. This is not a new problem:

"As the energy crisis deepened, the conviction grew that the main impediment to energy efficient building design was the lack of any real understanding of the complex way in which buildings respond to climate" (Clarke & Maver 1991).

2.1. Significance of the Early Design Tool

Today's building design tools allow the architect and engineer to build a virtual building and observe its performance. The first category comprises elements architects are more familiar manipulating and are the search objective of early design stages, such as orientation, building morphology, window size and location, type of shading devices, etc (Ochoa & Capeluto 2008). Performance criteria often focus on human comfort. For a human to be thermally comfortable, means to experience a condition of mind which expresses satisfaction with the thermal environment (ASHRAE Standards 1966).

Design alterations may be difficult once a design is fixed and carried onto the detailed phases; therefore decisions made using the early design tool are significant.

- The early stages of this process characterize themselves by a constant search for a design direction. But as demonstrated by specialists in design methods, decisions taken in those moments can determine the success or failure of the end product (Hari 2001).
- Most parameters are not assigned specific values early in the design process. Therefore, the designer is free to choose almost any value for the parameter of his current concern. As the design progresses, the previously assigned values may restrict the designer's freedom in choosing the values that are assignable to parameters considered later (Shaviv et al. 1996).
- The fragmented nature of the building process, in which no member of the design team considers the overall optimization of the indoor environment, further compounds the problem. Since the façade and fenestration design relates to different aspects of building performance (heating, cooling, lighting) and human comfort (thermal, visual), an integrated approach should be followed from the early design stage (Tzempelikos et al. 2007).
- Especially early design decisions will contribute to this. Performance assessment of different design solutions, e.g., building concepts, in the early design phase therefore is important (Hoes et al. 2009).

It has been assumed that the complex computer simulation design tool requires a complex and complete definition of a building. This makes the process of use of the tool in design slow and tedious, and because of the complexity of the inputs fraught with risk of data entry error.

Architects trying to use these tools are thus subject to evaluate finished alternatives using a trial and error approach. This slows down production schedules or forces them to depend exclusively on factual experience (Ochoa & Capeluto 2008).

Ochoa & Capeluto (2008) state that early design decisions are based on vague "ideas" that cannot be evaluated with tools that rely on exact data. And design tools that suggest solutions based on ideas are rare. This disadvantage can be seen in the planning of intelligent façades, where the number of possible configurations can be overwhelming and decisions made in early stages have profound effects on energy and comfort performance. Since early decisions are

very influential on a building's performance, the main objective is to select the best concept for later development in the detailed design process.

It is important to note that the performance analysis sketch approach of which COMFEN is an example is of a different nature than the 'forward looking' design tool proposed by Ochoa and Capeluto. As noted earlier, the basic philosophy of the performance sketch is to use the sophisticated detailed design performance analysis program in a simpler more constrained – sketch-like – manner. This has the advantage of ensuring that the sketch analysis calculation engine improves at the same rate as the detailed design analysis tool; and, it ensures that the information files generated during sketch design can be copied and re-used as the model and the design itself get more sophisticated. It has in common with the architectural sketch that it is an abstraction. It is quickly made and quickly disposed. Interoperability and long term retention of the information in the sketch model are not a priority. Speed of response and accuracy are of great priority. Like the architect's sketch, it can be returned to at any stage in the design process. Should it become necessary to explore a new idea for a facade during developed design, the sketch tool may allow a certain rapid analysis of new design options that can be returned to the comprehensive model once resolved.

2.2. Role of the Detailed Design Tool

Energy simulation programs typically require a substantial amount of input data, much of which is difficult to obtain, especially at the early stages of the design process (Clarke & Maver 1991). When it comes to the detailed design process, ideas and factors considered during the early stage are being developed, and specific and detailed information can be incorporated into the design. Precise specifications are available for all areas of the building's design. Details such as size of air conditioning equipment, exact window size and glazing combinations, etc (Aliakseyeu, Martens, & Rauterberg 2006) are known. An early design tool however suggests possible combinations of intelligent façades during early design stages. Its added value and advantages reside in inferring from a few conceptual and project questions, many and detailed alternatives that comply with codes dealing with energy efficiency. It is proposed that in this way the early design tool allows architects to choose the most suitable ones according to design intentions, knowing they are good starting solutions (Ochoa & Capeluto 2008). Therefore it's imperative to carry an appropriate and reliable concept into detailed design.

Because the majority of the energy use in a commercial building is for HVAC and lighting which maintains a comfortable working environment, an improved design of buildings may lead to significant energy reduction (Clarke 2001). However, these simulation tools also often have complex interfaces that require much time to learn. Both factors can distract from the design activity itself (Aliakseyeu, Martens, & Rauterberg 2006). Some have proposed that a design tool does not evaluate after the design is completed but rather:

A design tool would go beyond calculating the energy performance to address other building design considerations like comfort, economics, and aesthetics. Also, a design tool would help its users formulate appropriate design criteria and improve building performance as the design evolves (Papamichael & Ellington 1994).

The critical part in detailed design processes is to eliminate and minimise design defects as much as possible. There will always be defects when the building is completed. However, the seriousness of those defects really depends on the quality of the design. The objectives were to create a dynamic building envelope that would control solar gains efficiently, contribute to reduction in energy demand, and maintain comfortable indoor conditions (Tzempelikos, Athienitis, & Karava 2007).

A computer simulation model will never be exact compared to reality. Nevertheless, it provides the client with a realistic performance indication before the building is built. But Hensen & Augenbroe (2004) suggest that quality assurance procedures and better management of the inherent uncertainties in the inputs and modelling assumptions in simulation are two other areas where more progress is needed.

3. METHODOLOGY

In order to compare early design lessons and detailed design lessons in this research, a parallel operation of COMFEN and Energy Plus was set up. COMFEN is a single-zone based design analysis tool. The research compared the design recommendations resulting from COMFEN runs on alternate designs with design recommendations resulting from multi-zone simulations using Energy Plus. COMFEN is an interface that brings to the surface in the early performance sketch context many of the functions of Energy Plus. It is essentially an interface to the Energy Plus calculation engine. In this way it is genuinely a performance sketch analysis tool because it facilitates the use of a detailed analysis tool early in the design process. Designers using COMFEN and Energy Plus to undertake the early and detailed design process can therefore expect a significant cross-over in terms of re-usable input code. It can therefore be expected that the differences in the design advice Derived from use of COMFEN or Energy Plus will be a result of the differences in the manner of use (sketch vs. detailed performance analysis).

In the first stage of the comparison, four curtain wall designs are modelled in COMFEN (section drawings in Figure 1). Venetian blinds are permanently fixed on the façade exterior, at 45 degrees. Roller blinds were pulled down when windows experience high solar exposure 50°C and above (Figure 1). COMFEN simulates one zone at a time facing one orientation; each orientation has its individual zone (Figure 2).

Then the designs are integrated into the US Department of Energy's (DoE) three benchmark offices in Energy Plus. These are simulated under three different climate zones. The small office is 1 storey (510m²), medium office is 3

storeys (4,982m²), and the large office is 12 storeys (39,468m²). Figures 3–5 show the DoE benchmark offices that were used for the Energy Plus multi-zone simulations. Energy Plus does not provide an image in its interface when modelling, these three dimensional models are SketchUp’s representation of the detailed simulation.

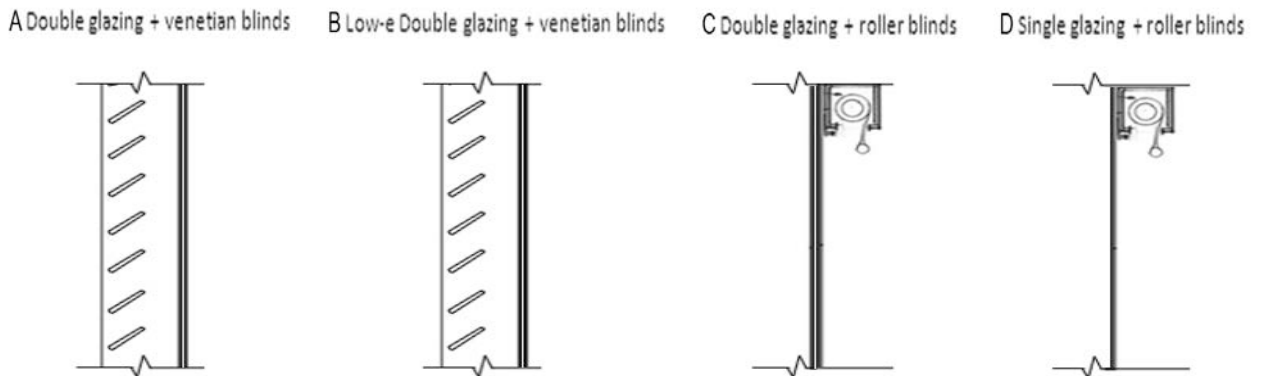


Figure 1: Curtain wall designs modelled in COMFEN (left of design = the exterior and right = the interior)

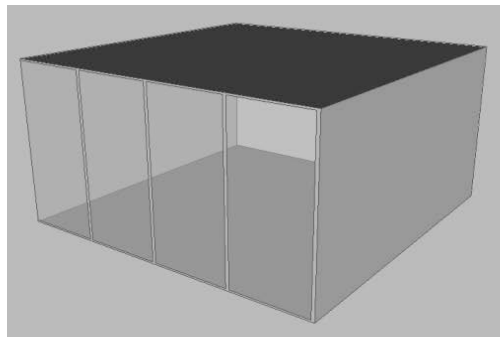


Figure 2: Single-zone in COMFEN – 4 zones were simulated for each façade design

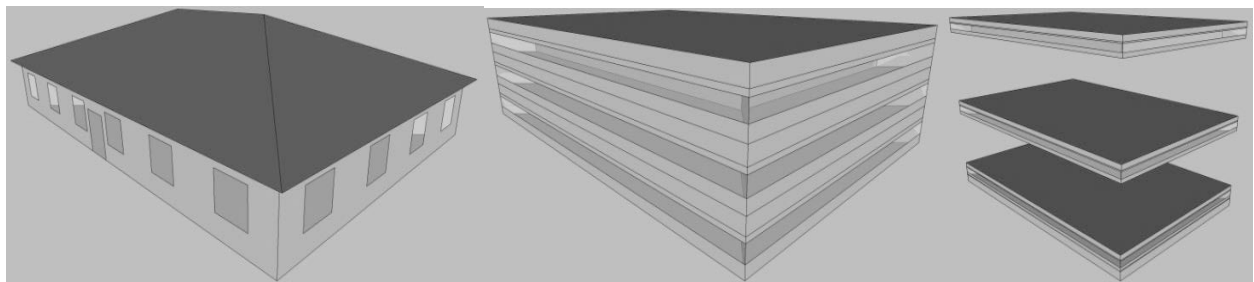


Figure 3: Small office – Energy Plus

Figure 4: Medium office – EP

Figure 5: Large office – EP

The small office only has one zone. The medium and large office have multiple zones, they have core zones (internal spaces) which do not have as much daylight exposure compared to perimeter zones. In the large office, Energy Plus divides up floors into top, middle and bottom for its calculation because energy use will vary in each floor level. The method of energy calculation consists of top and bottom floors (each multiplied by 1) plus middle floors (multiplied by 10) to represent the 12 storey benchmark large office. The façades’ energy performance was ranked from 1st to 4th in both programs and compared for the consistency test.

In the second stage of the comparison of COMFEN and Energy Plus, two curtain wall façade designs developed for a real building refurbishment by architects and engineers were modelled in each program. COMFEN does not have the option for modelling the double façades the design team had produced; therefore Energy Plus was used to run the COMFEN single-zone simulations with these features added. The DoE benchmark large office was modified in Energy Plus to the dimensions of the real building (15 floors, approximately 14,000m²) in Wellington, New Zealand; to test these real façade designs. The Figures below show the double façade design concepts developed by the design team:

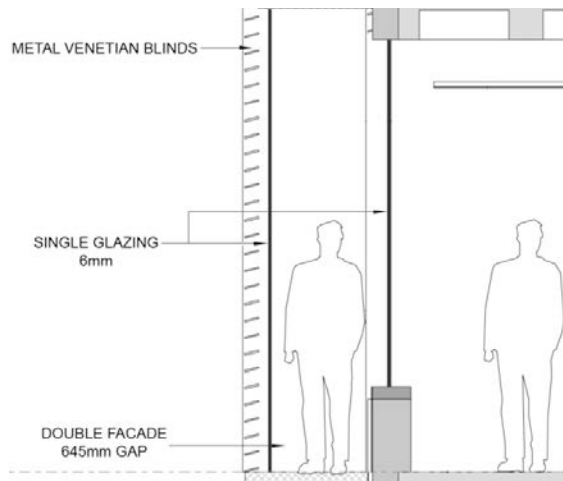


Figure 6: Double façade + Venetian blinds

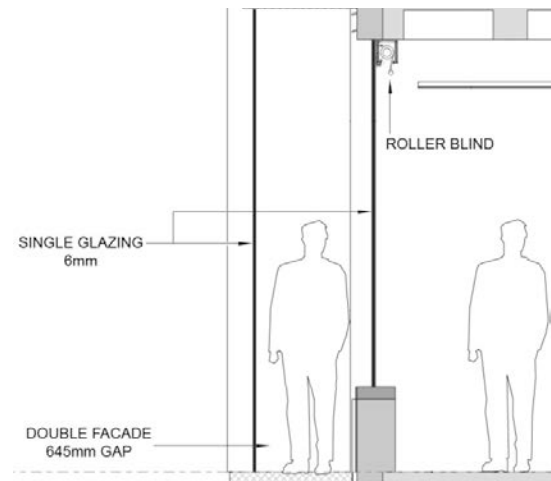


Figure 7: Double façade + Roller blinds

The test applied is again whether the COMFEN-based design decisions are consistent with the multi-zone simulations in the full version of Energy Plus. Specifically, the goal is to compare the annual energy use and loads predicted for each design as a single zone by COMFEN with that predicted for the whole building by Energy Plus. The consistency test cannot be that the energy use and loads are identical, even when 'normalised' per square metre or per occupant. This is because the fenestration will be far more significant for a single-zone than for a multi-zone building where some internal zones may have no direct contact with the outdoor air. The consistency test is that the fenestration system that is clearly the better system reported by COMFEN and by Energy Plus with a clear differentiation. If this is true then it is likely that the design decisions made using COMFEN will not be contradicted when the whole building design is modelled. Derived from computer simulation of single zone 'sketches' of the proposed building, it is vital this COMFEN information is consistent for architects to get a sense of each façade design's potentials.

4. SIMULATION RESULTS

The following sections are the results from the COMFEN and Energy Plus simulations. The energy performance of each façade design is ranked from 1st~4th with the lowest consumption of kWh/m²/year ranked 1st in each cluster of bars. Ranking of façades was determined in each category and climate zone (1st~4th goes from left to right in each cluster of bars). The COMFEN analysis graphed here is for building façades facing the sun – North in Wellington, South in New York City and Miami. The letters of each bar represent the fenestration types so that consistency equals letter order.

4.1. Simulations with DoE benchmark office buildings

In COMFEN the orientation of the façade in the single zone is critical because the glazing only faces in one direction. When the orientation of a façade is rotated it can be expected that the energy use will change. When this operation was forced in COMFEN, the west façade zone consumed the highest amount of energy, followed by the north, east and south façade oriented zones. This was consistent throughout all the climate zones tested. The very large difference between the COMFEN energy intensity (per square metre) and the Energy Plus energy intensity is a clear result of the focus of the COMFEN analysis on perimeter 'offices' – and their fenestration - whereas the Energy Plus analysis includes all thermal zones in a building including the internal zones which have far less interaction with the outdoor climate and hence are only driven by the internal heat loads due to electric lighting, equipment and people.

The DoE offices were simulated in COMFEN and Energy Plus. Figures 8~10 show the calculated energy consumption of each façade design.

Three cities with contrasting climatic characteristics have been tested for making a range of comparisons. These are Wellington New Zealand, which is in a mixed marine climate zone (Figure 8), New York in a cool-humid climate zone (Figure 9), and Miami in a very hot-humid climate zone (Figure 10).

A Double glazing + venetian blinds B Low-e Double glazing + venetian blinds C Double glazing + roller blinds D Single glazing + roller blinds

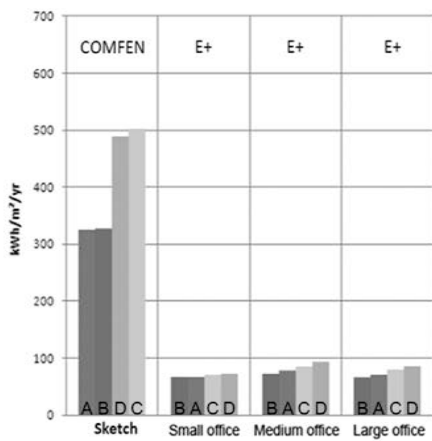


Figure 8: Simulated in Wellington

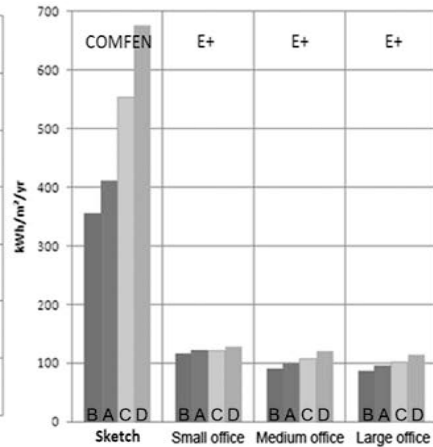


Figure 9: Simulated in New York City

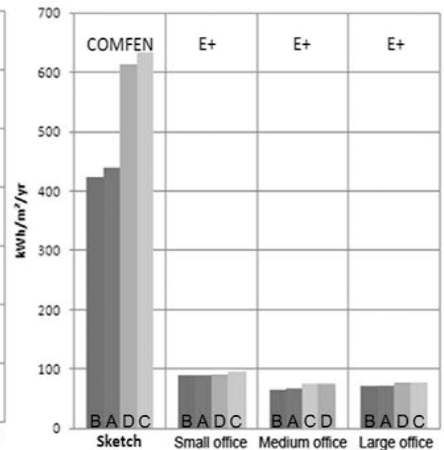


Figure 10: Simulated in Miami

The following discussion examines the consistency of the design recommendations between COMFEN and Energy Plus. The total energy intensity Figures and the percentage difference between each design option is compared. The percentage difference is the amount of energy a design consumed more than the higher ranked façade (i.e. 50% means the lower ranked façade consumed 50% more kWh/m²/year than the higher ranked façade). These differences are the basis for most design decisions. The intention is to determine whether design decisions made on the basis of differences shown by COMFEN are consistent with those suggested by Energy Plus.

In Figure 8 it can be seen that COMFEN calculates that in Wellington there is almost no difference between the 1st and 2nd fenestration options (Double glazing with Venetian blinds and Low-E double glazing with Venetian blinds). The difference was approximately 1%. The difference between the 3rd and 4th options is 4% (Single glazing with roller blinds and Double glazing with roller blinds). The ranking by Energy Plus of the DoE benchmark offices is not consistent with this COMFEN ranking. However, the ranking of the façade designs is consistent for each of the office types within the Wellington and New York (Figure 9) climates, and for these cooler climates, the office façades are also placed in the same order. For the warmer Miami (Figure 10) climate the ordering of the façade designs within the medium office is the same as for all three offices in Wellington and New York. But for the small and the large offices, there is a different order from best to worst performer.

Unlike the Wellington results, COMFEN in New York (Figure 9) shows a clear energy performance differentiation of the façade designs. The difference between 1st and 2nd was 15%; the difference between 3rd and 4th was 35%. The ranking of façade designs in the offices remained consistent with COMFEN. In Figure 10, for Miami, as with the New York climate the COMFEN calculations are largely consistent with the Energy Plus calculations for the DoE benchmark buildings. As noted above, the medium office does not fit this pattern.

4.2. Simulations with a real building

The distribution of energy consumption can be seen in Figure 11 for the double façade designs. This time the energy consumption was broken into the four major energy end-use components: Heating, Lighting, Cooling, and Ventilation. The single-zone ranking from COMFEN in the left two bar graphs is consistent with the multi-zone, with the Venetian blind design ranked 1st in the early and detailed design simulation.

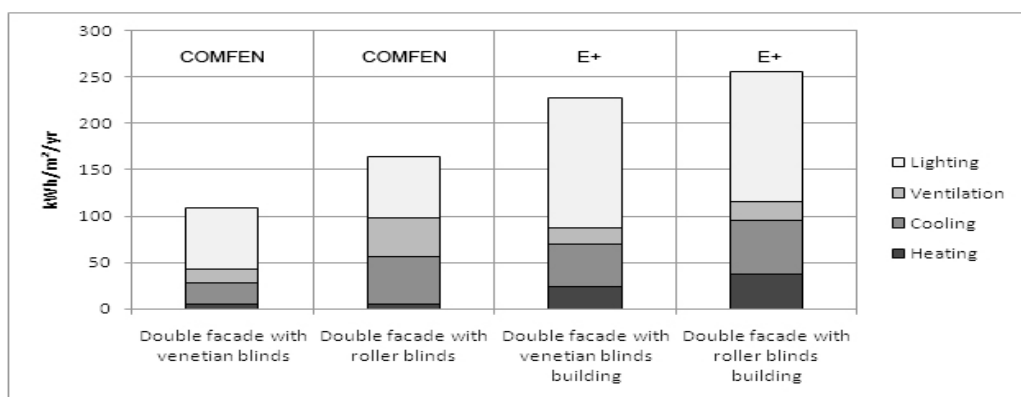


Figure 11: Single-zones and multi-zones simulated in Wellington, New Zealand

There was a clear differentiation of the energy performance of the façade designs. The type of blinds essentially determined the ranking. In the single-zone simulation, the difference between 1st and 2nd was 51%; in the multi-zone simulation the difference was 13% (Venetian blinds and roller blinds were only used on the north, east and west façade, apart from the south).

This time COMFEN design resulted in a lower energy use per square metre than Energy Plus. The real building's perimeter area has a much greater proportion of the total floor area than in the previous office examples. The effect of large interior zones with no connection to the outside can be clearly seen in the size of the lighting loads calculated by Energy Plus as shown in the right hand two bar graphs in Figure 11. The much larger heating load and lower ventilation load for the detailed Energy Plus model is more difficult to explain.

CONCLUSIONS

COMFEN and Energy Plus façade design ranking comparisons determined the relationship between early design lessons and detailed design lessons. In summary, the result of this set of tests is a demonstration that COMFEN and Energy Plus often, but not always, produce predictions of energy performance that are consistent across different design scenarios. This suggests that use of sketch performance analysis tools requires a careful scrutiny of the design options.

Architects rely on early design tools. The need for early design tools to be reliable is essential because it is too late to make changes after the building is completed; where changes to remedy defects could cost thousands of dollars. Especially with fully glazed façades, which require immense amounts of energy to condition the associated interior space, it is vital to get the design right from day one of the building project.

To use the early design performance analysis sketch well requires experience. This analysis suggests that use of early design tools like COMFEN needs care to ensure that design investment decisions focus only on those aspects whose performance has been tested, and to use care when extrapolating the design message to the whole building. At present, extrapolation of the performance sketch to the whole building could potentially mislead architects during the early design process.

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