IQP BJM-003a

# Concept for Assessing Factors Relevant to Performance-Based Building and Fire Code Adoption

An Interactive Qualifying Project Report

Submitted to the Faculty of the

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirement for the

Degree of Bachelor of Science


By

**Matthew Cogswell**

mjcogswell@wpi.edu

**Melody Wang**

melodywang@wpi.edu

**Advisor:**

**Professor Brian Meacham**

bmeacham@wpi.edu

# Abstract

Research was conducted to identify and compare factors which might be relevant to performance-based building and fire safety code adoption in two cities: Hong Kong and New York City. Factors include education, history, technology, social, and regulatory considerations. Using factors identified in the literature review, a first-order decision model was developed using the analytic hierarchy process (AHP) to the rank relevancy of the factors and to identify the best code option for each city. While the outcome suggests that performance based codes could be appropriate for both Hong Kong and New York City, analysis suggests that a combined performance and prescriptive code approach might being the best option. Further analysis, with broad stakeholder input, is recommended.

## Table of Contents

## List of Figures

## List of Tables

## Acknowledgments

The IQP team would like to give thanks to their project advisor Professor Meacham. Throughout the project when roadblocks were reached he helped us to find solutions. Also, because of his experience and expertise in the topic area, the IQP team was able to have a professional in the field of study to provide perspectives and assistance. Without his guidance and help this project would have not been possible.

## Authorship

Throughout the project the authors evenly split the workload between them. With respect to the AHP models Melody Wang worked on the Hong Kong model while Matthew Cogswell looked into the New York City Model. When the results were obtained it was a joint effort to write the paper. Both Wang and Cogswell had influence on every section.

## Executive Summary

Building and fire codes provide the minimum standard that building construction has to follow in order to achieve various safety goals. Among all the safety goals, fire safety is an important component because the complexity of the causes of fires, damage that fire accidents may cause, and hazard to life. In most countries, fire safety standards are adopted to help prevent fire accidents from happening and minimized impact when accidents occur.

Building and fire codes can be categorized into two types: prescriptive and performance based. A prescriptive code is a code that prescribes exactly what has to be met in regards to fire protection systems, egress plans and so on. A performance-based code is a building code that states the safety goals, and references approved methods that can be used to demonstrate compliance with their requirement, without specifying exactly how to comply. In other words, the difference between a prescriptive approach and a performance approach is that prescriptive describes an acceptable solution while performance describes the expected and required performance.

With such multifaceted content, a prescriptive code is usually a document with several hundred pages. A prescriptive code offers direct interpretations or quantitative values for various construction requirements, which does not require fire protection engineering knowledge to interpret it. A performance code, on the other hand, relies on engineering analysis to measure if a certain building meets the design goals or not. It is also more suitable in an innovative building environment and may potentially save costs in construction and operation. Prescriptive and performance codes have their own advantages and disadvantages. This project compares these

two types of fire codes for the purpose of selecting the better alternative for Hong Kong and New York City based on background research of the cities and a decision-support model.

The methodology section identifies the criteria used for decision-making related to the type of code. The top level decision criteria are Education, Technology, Social, Regulatory, and History, and each of the criteria have several sub-criteria to demonstrate their impact in detail. The criteria include both accelerators and decelerators relative to performance based code implementation.

The approach used to assess relevancy of criteria and sub-criteria (factors) of performance code implementation is the Analytical Hierarchy Process (AHP). AHP is a mathematical decision making method based on pairwise comparison and matrix theory. SuperDecision software is applied as a tool to construct the AHP model in this work.

The result of the AHP model shows that a performance-based code is theoretically a better option than prescriptive code for both Hong Kong and New York City. However, the major decelerators such as "lack of training for code official" are slowing down the pace of performance based code implementation. In addition, there are certain limitations for both performance based code and prescriptive code according to the data output. Therefore, it is suggested that an ideal way to solve this problem is to have a combined code that has advantages of both prescriptive and performance based code.

Future advancements on this work can be made by conducting surveys to stakeholders that are involved in or affected by building code and life safety decision-making.

# Section 1: Background

This project explores issues which might influence a jurisdiction's decision to remain with a prescriptive-based building code or transition to a performance-based building code, and presents a first-order decision model that could be used as a guide for jurisdictions faced with such as decision. The study developed from an initial focus on trying to understand difference in approaches to building regulations between China and the USA. Given challenges in identifying the type of information that was desired, the effort ultimately focused on why a jurisdiction in China or the USA may or may not adopt a performance code. The focus was further refined to Hong Kong and New York City. From the literature that was reviewed, factors which may be important to the decision of performance code adoption were identified. A first-order decision model was then constructed, using these factors, to help assess the relative importance of each factor to the decision. The model was tested by the authors, using their judgment, based on literature that they reviewed. The model could be enhanced in the future with additional research on factors and weighting performed by experts, regulatory officials and other stakeholders in the building regulatory process. This section outlines how the final project focus was developed. Subsequent sections outline the literature which was reviewed, the decision model and outcomes.

## 1.1. Initial Focus and Refinement of Scope

The initial basis for this project was to explore differences in building regulatory approaches in China and the USA as reflected in requirements for the 2013 Solar Decathlon

China competition (SDChina.org). The Solar Decathlon (SD) competition is a collegiate competition that has been in existence since 2002 (SDChina.org). The U.S. Department of Energy challenges teams to construct solar-powered houses that are cost-effective, efficient, and appealing. This competition is held biennially in the United States, but has expanded globally. In 2013 Solar Decathlon China (SDC) will be held in Datong, China. The Solar Decathlon China competition will be put on by both the U.S. Department of Energy, the China National Energy Administration, and organized by Peking University. This Solar Decathlon competition will be in support of one of the Sino-US energy programs. Worcester Polytechnic University is competing on Team BE-MA-NY, comprised of Ghent University and New York University Polytechnic Institute, against twenty-two other teams in China. Each team has the difficult task of creating a solar powered house that will be judged on numerous different factors.

One of the first observations in terms of differences between the SD competition and the SDC competition was differences in building code requirements. Because one aim of the project is to design a building which meets competition rules as well as met USA building code requirements (specifically for WPI the Commonwealth of Massachusetts requirements), determining differences and the bases for the differences between USA and Chinese building code requirements was the starting point.

The first step was to obtain relevant codes from China and the USA. These were identified as the *Code for Design of Civil Buildings* (Ministry of Construction of the People's Republic of China, 2006) for China and the *International Residential Building Code* (IRC, 2012) for the USA. It was noted that several differences existed, including the structure of the codes. Like the USA, China does not have one unified code that encompasses all aspects of a building. For example, they have a separate set of codes for building, fire protection and electrical installations and more. In addition, they have different building classifications than in the USA, and there are other factors driving the type of residential housing which is prevalent. Some of these issues are outlined below.

In addition, because the BE-MA-NY team had decided to use a non-traditional building material – a fiber reinforced polymer (FRP) composite panel, which serves as structural support as well as interior and exterior walls – research was required to determine how to obtain approvals for the design in the context of both codes. This led to a code review and summary with respect to the Massachusetts State Building Code (MSBC, 2012), as reflected in Appendix 3, for comparison with Chinese codes. Requirements in the China's *Code for Design of Civil Buildings* were quite different, including requirement for fire resistance rating of exterior walls, which is not a relevant factor in the MSBC for the size of building and plot. The house consists of an open concept floor plan that includes: two bedrooms, one full bath, kitchen, glass roof foyer, and entertaining area. The house is 100 square meters, and is completely energy efficient.

Figure 1: Team BE-MA-NY solar house

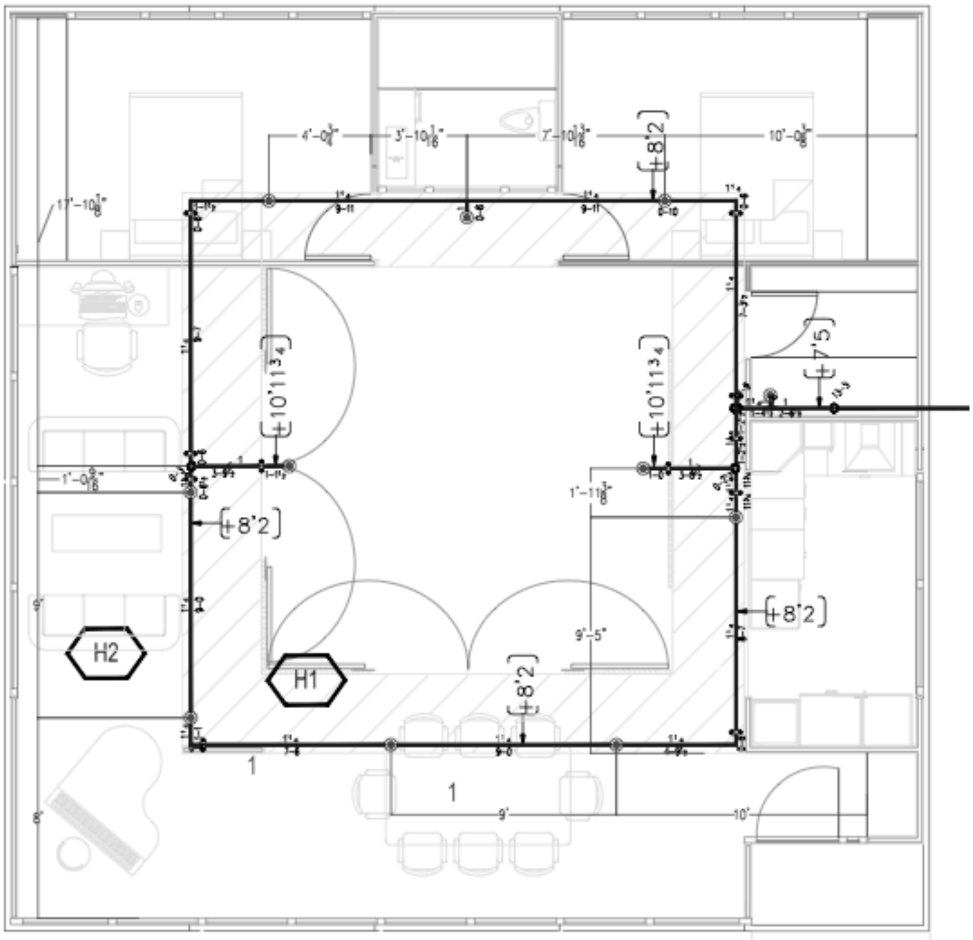



Figure 2: Solar House Floor Plan

Figure 3: A view into Solar House Foyer

Based on code analysis, a request was made to the SDC organizers to be allowed to apply USA codes, specifically the *International Residential Code* (IRC), upon which the MSBC is based. This request was granted. As such, further assessment of the codes differences between China and the USA, for the purpose of the SDC competition, was not needed.

However, this activity identified a number of other issues for consideration. First, as noted above, there are differences between China and the USA in terms of residential buildings. One of the major differences stems from the amount of living space available. Because China is facing severe overcrowding, construction is forced to go vertical. When looking into past statistics, the median livings space per person was 675 square feet in the United States and 269 square feet in China (Li, 2011). From these statistics it can be seen that the rise of high rises in China resulted in much smaller living spaces than the one to two family dwellings in the United States. With the population only continuing to grow, the buildings will only get taller, and more confined.

The issue of vertical development and dense urban environments led to exploring differences in regulatory approaches to high-rise residential buildings. However, limited data were available in the English language about the situation in China. Nonetheless, a building code comparison for high-rise buildings was obtained from Fang Li, a fire protection engineer in China with the firm RJA. The whole study cannot be reproduced for proprietary reasons.

While information about the overall Chinese situation were lacking, significant literature about the situation in Hong Kong was identified. This then led to a decision to focus on two cities of similar size, rather than trying to encompass entire countries. This resulted in selection of Hong Kong and New York City – two cities of somewhat similar size and demographics. New

York City has a population of 8,244,910 as of 2011 (U.S. Census Bureau), and is 468 square miles (U.S. Census Bureau). Hong Kong is 382 square miles with a population of 7,071,600 (World Bank). Using these statistics New York has 17,618 people per square mile, and Hong Kong has 18,512 people per square mile. Because of the similarity of the population densities these cities seemed adequate for our study.

Figure 4: High Population Density in the Streets of Hong Kong


Figure 5: New York City Skyline

During the time spent doing research on building and fire codes in Hong Kong and New York, one of the most written about subjects identified was the issue of performance-based building and fire codes. In particular, one issue identified is the relative benefits of a performance-based code for approval of innovative material, such as the FRP panels in the SDC competition, versus trying to obtain approval through a prescriptive code system. This led to formation of the research question around the issue of adoption of performance-based building codes. Specifically, the revised goal was to explore reasons why both New York City and Hong Kong do not have performance-based building and fire codes, even though they provides more design flexibility than prescriptive codes, and explore what form of code is the best both cities.

## 1.2. Project Statement

Building and fire codes provide the minimum standard that building construction has to follow in order to achieve various safety goals. Among all the safety goals, fire safety is an important component because the complexity of the causes of fires, damage that fire accidents may cause, and hazard to life. In most countries, fire safety standards are adopted to help prevent fire accidents from happening and minimized impact when accidents occur.

Building and fire codes can be categorized into two types: prescriptive and performance based (Meacham, 1997; Hadjisophocleous, 2000). A prescriptive code is a code that prescribes exactly what has to be met in regards to fire protection systems, egress plans and so on. A performance-based code is a building code that states the safety goals, and references approved methods that can be used to demonstrate compliance with their requirement, without specifying exactly how to comply. In other words, the difference between a prescriptive approach and a performance approach is that prescriptive describes an acceptable solution while performance describes the expected and required performance.

Although modern prescriptive codes have a much longer history in most countries than performance codes, there are several limitations to the prescriptive approach. It is not only limiting in design and construction freedom, but is also accused of resulting in code-mandated repetitions (Hadjisophocleous, 2000). About twenty years ago, performance based designs became an alternative to the prescriptive requirements. Later on, discussions had been made of whether we should have a standard code system for the performance-based designs.

Tracing back to research from the later 1990s, it was stated, “the movement towards performance based codes and standards has become a world wide effort”. For instance, a White Paper entitled “Performance-Based Codes and the NFPA” was prepared in the United States in January of 1994 (Puchovsky, 1994). After all those years, has performance based code really become the mainstream of the code and standard as we visualized it to be? If not, what are the barriers that slow down the implementation of the performance based code? By identifying the elements of a performance based standard development, which step is the most difficult to realize?

In order to give more specific vision of the research study, New York City and Hong Kong become the major cities to conduct the research with. There are certain similarities between these two cities such as over dense population and significant numbers of skyscrapers. Those two cities also have millstone events happened in the past twenty years that might have interfered the performance based code implementation. In order to analyze the code implementation of both cities, the authors made it their goal to assess whether it was possible to measure the distance between visualization and implementation for a performance-based code in these cities. Using research and statistical analysis, performance and prescriptive based code options where compared against each other in order to see which one would apply better for both cities, and why this is.

## Section 2: Literature Review[1]

In this section the authors compiled the sources, reviewed and identified the most important topics in respect to their research question. Among the sources they reviewed, several factors repeatedly appeared. These included, education, technology, history, social support and regulatory systems. These factors are discussed below and related to the research question. Once the relationship between the factors above and the research question was understood, the authors reviewed their literature sources again, this time with respect to what influenced the factors (e.g., what influenced regulatory system or education). Again, a set of reoccurring factors or attributes were found. Discussed in the following, are the top-level factors and sub-factors (attributes) which have been determined to be important to the research question.

### 2.1 Building Code Format

#### 2.1.1 Prescriptive Code

A prescriptive code can be defined as "a code that dictates how a building must be built, what materials can be used, how they may be used, and when they can be accepted" (Meacham, 2009). The current building codes in Hong Kong and New York City are both prescriptive based codes. An understanding of prescriptive code is necessary in order to determine whether it is necessary to shift the current code from prescriptive to performance based.

The advantage of a prescriptive code is that it is very straight-forward in terms of requirements (Begley, 2004). It offers direct interpretations or quantitative values for the

---

[1] *Note- numerous sources will be analyzed more than once because of their specific use in each criterion

dimension and load capacity instead of performance criteria (Tavares, 2008). In addition, it does not require code officials to have educational or training experience in fire safety engineering design (Tavares, 2008).

However, problems with prescriptive code were found in the development of modern building industry. Modern building industry focuses more on green and sustainable construction. However, the sustainable design objectives usually does not get approval by the prescriptive code requirement (Hofmeister, 2010). There is also complaint about the prescriptive code being redundant and difficult to understand. This was noted by Law (1991) who stated that one reason England moved to performance is that the prescriptive code was “understood mainly by lawyers”. The New York City Fire Code has 640 pages with 45 different chapters (nyc.gov, 2008). Moreover, it is also challenging to have a cost-saving fire design with a prescriptive code (Tavares, 2008). In the case of a typical prescriptive code design restrictions on, fuel loads, fire suppression systems, and fire detection systems may be required at the same time (Babrauskas, 2000). In the end, it may meet the fire safety objectives but it may not be the most effective design for that particular building.

### 2.1.2 Performance Based Codes

As with the need to understand prescriptive codes, it is also necessary to understand performance codes and what their pros and cons are. Understanding that performance based design is what is regulated by performance based fire codes is also crucial. Society of Fire Protection Engineers (SFPE) defines Performance Based Design as, “an engineering approach to design elements of a building or facility based on performance goals and objectives, engineering analysis, scientific measurements, and quantitative assessment of alternatives against the design goals and objectives, using accepted engineering tools, methodologies, and performance criteria" (Neale, 2010). What this means in simple terms is the ability to define a goal that is important to Society, and permit it to be achieved in any appropriate way the engineer would like, so long as the performance is demonstrated and proven acceptable to all parties involved. Performance Based Designs (PBD) are growing in acceptance internationally and currently many countries have some sort of performance option (Bukowski, 1995). Examples of these countries are Sweden, U.S., U.K., New Zealand, and Australia. Before New York or Hong Kong consider fully implementing a performance-based code it is beneficial to look at the pros and cons.

Performance-based codes allow for use of PBD as the focus on goals and objectives rather than detailed prescriptions. The general structure of a performance-based code is composed of three sections: Codes, Standards and Practices, and Evaluation and Design Tools (Meacham, 1997). Codes are composed of the goals, objectives, and performance requirements that a certain society wants the buildings to be held accountable for. This code format can be seen in figure 6. Standard and Practices refer to methods in which these requirements can be complied with. Evaluations and Design Tools explain methods on how to develop, review, and verify different designs in accordance with the correct engineering standards. An example of a basic performance based design and analysis procedure can be seen below in Figure 7 (Meacham, 1996).

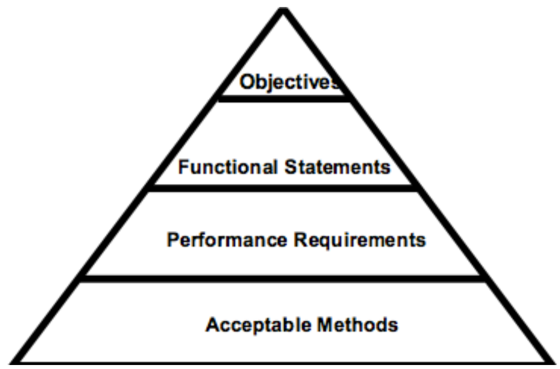



Figure 6: Hierarchy of Performance Based Code

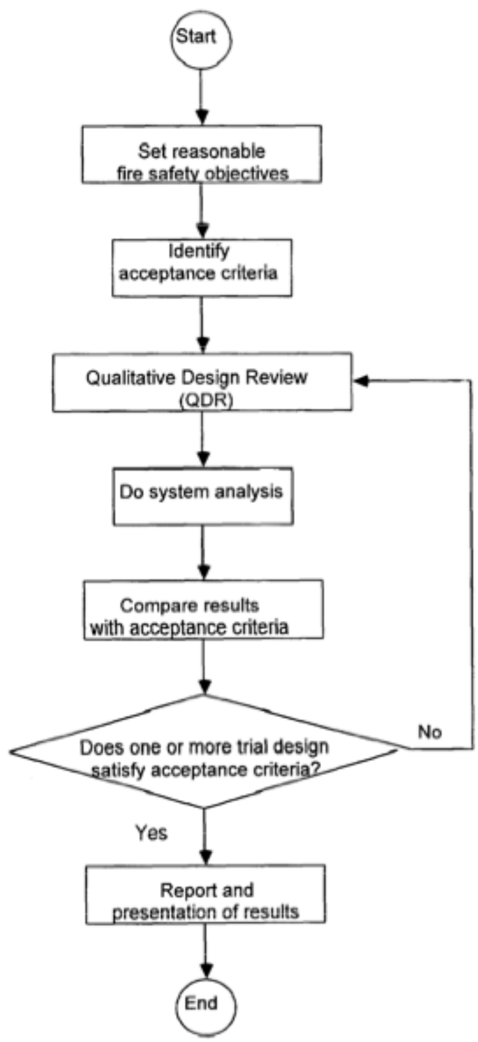



Figure 7: Basic Analysis and Procedure for Performance Based Design

Performance based building and fire codes have the opportunity to bring many advantages, including, cost, flexibility, innovation, and clarity. One major component that is considered when changing anything, however, is cost. Higher flexibility with a performance-based design allows for cheaper costs of overall construction (Tsui & Chow, 2002). Unlike prescriptive codes, performance-based codes allow the architect to design the building any way he would like, which can open the doors to many cost saving designs. Performance codes also open the door to a lot more innovation that previously was hindered by stringent prescriptive codes. These new building will also be very clear in their fire objectives, and will be able to have concrete ways of quantifying their designs (Waters, 2000),(Tsui & Chow, 2002). Performance-based codes will also allow for the use of new fire engineering technology as it becomes available. One major benefit that prescriptive code could never do is the ability to allow for different countries to have the same code (Tsui & Chow, 2002). This would allow for much easier international consulting and construction. These are not the only benefits to a performance based, but make up a large amount of the most important factors.

### 2.1.3 Accelerators and Decelerators for Building Codes

A change as big as switching to a completely different fire code will bring with it a lot of factors to consider. When looking into any type of change there are always good things and bad things that come with it. In order to analyze whether the change is going to be beneficial or not the good factors can be compare against the bad. In most cases the good factors are thought of as accelerators to the implementation of the change, and the bad as decelerators. The authors considered accelerators to be factors that pushed for the implementation of a performance based code, and decelerators to be factors that hindered the implementation.

One reason that performance based codes have not been adopted everywhere is because there are certain barriers that are rather difficult to get by. One issue is the difficulty with creating the code, and obtaining what is necessary to assess them (Tsui & Chow, 2002). This relates back to the education section. As stated previously, the education of the code officials, and everyone involved in the fire industry needs to be better in respect to fire protection engineering (Meacham, 1997). If this does not happen then many of the people dealing with the code will have difficulty understanding them, which could result in problems. Another issue relates back to the famous quote made by Hammurabi. This quote touch's upon responsibility, and shows how a performance based code puts a lot more responsibility on the people involved in the design (Waters, 2000).

Another problem is presented when a building that was built with a performance-based design is to go through renovations (Begley, 2004). In a prescriptive building a renovation is rather easy because components that cannot be destroyed or moved can be identified. However, as established, a performance-based design allows the design to be done any way the engineer wants. This means that detailed records will need to be kept in order to understand what is important to the design (Begley, 2004).

Many of these barriers were identified by Lucht (1991) and are still of concern. Specifically, Lucht noted lack of defined fire safety goals in current building codes, resistance to change, lack of necessary education, ineffective transfer of new engineering methods, economical incentives and disincentives, apprehension from lawsuits, unwillingness to adopt innovation as barriers, a need for competitive universities /industries/ governments, new code concepts, adoption of new engineering technology, successful evaluation of engineering tools as factors needed to overcome the barriers. Problems like these will be considered with the implementation of a performance-based code, and will be weighed against the pros in order to see whether a performance-based code is necessary.

## 2.2 Education

The direct link between education and the overall goal of implementing a performance-based fire code can be defined as, "the educational requirements that will be of importance to the process of implementing and enforcing a performance-based fire code." Several different educational requirements for implementing performance-based code were found throughout our study. The most pertinent and common are analyzed.

Education of the code officials seemed to be the most discussed topic in the literature. A code official is the authority in charge of reviewing the building designs and deciding whether or not the building meets the necessary code specifications. The implementation of performance-based fire code will need a group designated to uphold the code, this is what the code official's job entails. Currently, the building officials in both Hong Kong and the United States work with a prescriptive code in which there is an option that allows the creation of a performance-based design as an alternative approach to strict code compliance if the prescriptive code cannot be followed (Chow, 2002; Neale, 2010). In the United States, engineers are submitting support for their designs which can include complex engineering analysis and computational modeling to get their designs accepted ( Bukowski, 1995). This illustrates that code officials will need to be sufficiently educated in the science of fire protection engineering if a performance-based code is going to be successfully implemented.

However, while it may be difficult at first to raise the educational needs, the process of submitting performance-based / alternative designs to code officials for review and approval has long-term benefits. Because the alternative approach has been available for several years, code officials have gotten significantly better at analyzing and accepting them ( Bukowski, 1994). This could be good for future implementation of a fully performance-based code. The better-educated code officials are on issues of performance-based design the easier acceptance and implementation of a performance-based building code will be in the long run.

Education was noted as a particular need by the Inter-jurisdictional Regulatory Collaboration Committee (IRCC), a group comprised of building regulatory agencies of countries which have developed and implemented performance-based building regulations (www.IRCCbuildingregulations.org). In their 1998 Guidelines for the Introduction of Performance-Based Building Regulations (IRCC, 1998), education was highlighted as one of five fundamental areas of focus, along with technology, public policy, support frameworks and process management. With respect to education, two crucial issues apply. Firstly, because the code is being changed a need for education is required, the greater the change the greater the need for education. Secondly, without the correct education program available there will not be many options for the applications of a performance-based code.

Educating the engineering workforce is also important, and one of the first steps before implementing a performance-based building code should be the further education in fire protection engineers (Meacham, 1997). One country that had an advantage with respect to performance-based codes was Sweden, because in addition for education practitioners, they also educated their fire service personnel (Bukowski, 1994). All of Sweden's fire officials are educated in fire protection engineering; this was beneficial when they made their change from a prescriptive to a performance code (Bukowski, 1994).

Similar to the situation in Sweden it is helpful to analyze and learn from other countries areas as well. In New Zealand, for example, research conducted by the Centre for Advanced Engineering at the University of Canterbury led to the creation of New Zealand's Code of Practices for performance based design ( Bukowski, 1994). The creation of the code of practices led to the formation of a highly desirable graduate program in fire protection engineering ( Bukowski, 1994). Examples like this point to the fact that universities that study fire protection engineering are extremely beneficial for the country implementing the new code. Formation of graduate programs can lead to research, and development of future fire protection engineering techniques. Because of the benefits of universities it seems evident that any country implementing a performance-based code should have significant connections with universities. In work done by another IQP project (Cannif, et. al., 2012) that looked into performance based fire code in Brazil, Korea, and Poland it was agreed education is a critical aspect. From this information it is easy to realize that the education of everyone involved in the fire service industry needs to be high in fire protection engineering if a smooth transition is going to take place.

## 2.3 Technology

When looking into the implementation of performance based fire code there are many different technological factors to consider. Many of these stem from the need to be able to define, measure and/or calculate performance (IRCC, 1998). These range from the introduction of the computer, to the amount of fire labs available in a region for testing and research. Many technology-related factors were revealed during the literature review, but only those factors that appeared often are considered here.

Technology in respect to fire laboratory presence and capability came up in the research. When transitioning to a performance-based code it is helpful to have fire labs, which conduct research and do testing on fire materials (Meacham, 2009). Because of this assumption, the convenience of fire labs for each city was taken into consideration. In China, the China Academy of Building Research (CABR) performs tests in many different construction fields. The CABR has 14 research institutes and 77 labs, which encompass fire prevention as one of their areas of research. Because of the high number of research institutes that are able to deal with fire prevention in China it seems that Hong Kong will have plenty of support in research and testing. The United States is home to the headquarters of the largest testing laboratory in the world, Underwriters Laboratories (UL) located in Northbrook, Illinois (Underwriters Laboratories, 2013). Laboratories like UL can help research and test materials in order for them to met specification in the code (Underwriters Laboratories, 2013). Because of New York's accessibility to UL it is evident that if there were a change in code then New York would be able to conveniently use UL as a testing laboratory. As can be seen from the information both cities are reasonably prepared in terms of testing and research.

As technology increases so does the amount of innovative building designs. For example, buildings in China are continuously becoming more complex by incorporating green components, extreme height, multi-uses, and underground subway stations (Chow, 2012). Unfortunately it is not easy for these types of buildings to meet prescriptive codes. Because of the rate of technological evolution it is necessary to make sure that there are fire codes that can accommodate these new types of construction. One solution to this is performance-based design, which is currently being used in places like Las Vegas casinos when prescriptive codes cannot be met (Neale, 2010). Performance based codes are able to support these technologically unique buildings (Waters, 2000). Because of this, implementation of a performance based fire code will be beneficial to the continued technological growth of our buildings. As technology increases it is important that a building code is available to satisfy the new types of designs.

## 2.4 History

When transitioning from a prescriptive based fire codes to a performance based fire code the individuals in charge will no doubt take a lot into consideration. Looking over past incidents, and the history of the building code in the respective country will be useful when trying to see what has already been done. Through this process past mistakes and trends can come up, which will help with a smooth transition.

The history behind building codes in our world dates back a very long time. The earliest use of performance codes can be traced back to Babylonia (Waters, 2000). In the codes of Hammurabi there is a famous quote that is frequently referenced, it states, "In the case of collapse of a defective building, the architect is to be put to death if the owner is killed by accident; and the architect's son, if the son of the owner loses his life". This quote brings up some of the responsibility issues related to performance-based code, which will be further analyzed in the Performance Based Code section. Building codes can also be seen in ancient Rome when Julius Cesar and Augustus Cesar set specifications for the maximum height of buildings (Waters, 2000). Situations like these arose throughout history, in some cases for planning purposes and in some cases as a result of events (e.g., building requirements in London after the great fire of London in 1666) and became more common as the years went by.

Specifically in the United States, building codes of a sort were applied even before the formation of the country. As early as the late 1600's, for example, New Amsterdam had requirements for buildings which related to fire safety (Meacham, 2009). Upon the formation of the United States, the responsibility for building codes was given to states. In deciding to form a federation of states, the drafters of the U.S. Constitution limited power delegated to the federal government and retained significant power for the states. One power that the states had was police power, which encompassed building codes. Because of this, the state government is responsible for the regulation of building codes as opposed to the federal government. However, given the differences in government between states, this also means that there are variances between the building codes enforced in different states.

It is widely considered that the development of legitimate prescriptive building codes began around the 19$^{th}$ century (Waters, 2000). In the early 1900's three different model building codes were published by three organizations (Building Officials and Code Administrators International (BOCAI), Pacific Coast Building Officials Conference, Southern Building Code Congress International (SBCCI)) for possible adoption by states and local jurisdictions, in addition to fire codes published by a fourth organization, the National Fire Protection Association (NFPA) (Meacham, 2009). Because each state could implement whatever they chose for building regulation, this understandably made it difficult for industry when dealing with different parts of the country at once. Fortunately, the three organizations which drafted model building codes for states to adopt (BOCA, ICBO and SBCCI) realized that it was necessary for them to unify into one creating the International Code Council (ICC) (Meacham, 2009). Currently the ICC and the NFPA are the two organizations in the United States who are developing model building and fire codes. Both the ICC and NFPA have prescriptive and performance codes that are available for adoption. As stated previously it remains up to each specific state as to which code they adopt.

As noted above, many large fires and problems lead to advances in our current regulations and codes (Shelhamer, 2010). For example, in 1835 a massive fire wreaked havoc on New York City and demolished 674 buildings, which led to changes in type of construction, and general fire resistance (Shelhamer, 2010). Because of this, the Great Fire of 1835 did not spread to any recently constructed buildings (Shelhamer, 2010). Numerous other large loss fires over history resulted in changes to building codes (NFPA HB, 2008; Tubbs and Meacham, 2007), including such recent events as the World Trade Center (WTC) collapse in 2001 and The Station nightclub fire in 2003. After the collapse of the towers a review was done on it that has resulted in multiple advancements (Meacham, 2009). Major outcomes of the WTC investigation included recommendations for performance-based design of structures against fire, more resilient and reliably fire protection systems and the use of elevators for evacuation. These types of code changes were taken into consideration in our study because when implementing a performance-based code it is necessary to see what has been done before proceeding.

Hong Kong is an interesting case because of its history. Specifically, how Hong Kong was under British control. Because of this, many of Hong Kong's building codes can be traced back to the United Kingdom (Chow, 2002). However, since it has become part of a special administration region (SAR) of China there has been a lot more explorations into new ideas (Chow, 2002). Currently, there are four codes that make up Hong Kong's fire codes: Means of Escape, Fire Resistance Construction, Means of Access of Fire Fighting and Rescue, and Fire Service Installation (Chow, 2002). Like the United States, these codes are prescriptive (Chow, 2002). By understand Hong Kong's current codes, and their origins it will be easier to look into the past to gain education into things such as the regulatory system, code amendments, and research. This will allow for an easier transition to performance-based fire code.

## 2.5 Regulatory System

A regulatory system is a function of legal system, roles and responsibilities of various parties (government, industry, practitioners, etc.) and balance between government and market. The regulatory system is one of the most important aspects of performance based code implementation since people who are involved have the actual power of making decisions rather than giving support or opinions. Discussion related to issues associated with different regulatory systems can be found in Meacham (2009). In some cases, these factors may have also slowed down the transition to performance-based code.

In Hong Kong, the regulatory system of fire safety falls under the realm of the Building Department of Hong Kong. Currently, the passive fire protection system is overseen by the

Building Department of Hong Kong while the active fire protection system is governed by the Fire Safety Department of Hong Kong (Tsui). In September 2011, the Code of Practice was first issued after a consultancy study on the engineering design approach in regards to complying with the fire safety code requirements (Kong, 2011). The Code of Practice contains both performance and prescriptive requirements (Kong, 2011). The lead consultant party is Ove Arup & Partners Hong Kong Ltd. appointed by the Buildings Department (Kong, 2011), and a committee that oversees the code. The committee includes a variety of experienced building industry stakeholders including, structural engineers, building surveyors, architects, fire officers, and higher institutions (Kong, 2011).

As noted above, building regulation in the USA is the responsibility of states. However, they can also delegate that authority to other jurisdictions, such as counties, cities or towns (Meacham, 2009). In New York, The New York State Uniform Fire Prevention and Building Code act was enacted in 1981 (Cassano, et.al, 2010). Before this the local government controlled the adoption, administration and enforcement of codes. There was also no fire code in certain area, which created great confusion within the different municipalities. In 1984 a law was passed that forced every municipality except for the city to enforce the state code. This meant that the city was in full control of their fire and building codes. Every local government was supposedly responsible for their codes, but in a way the state was in control because they were forcing local governments to adopt the New York State Code. This changed somewhat following the events of September 11, 2001, as New York City decided to adopt the ICC codes, as did the State of New York. Currently both the state and city have adopted the ICC's codes, but the state has its own provisions as does the city.

## 2.6 Social

The decision making process of building code is not only driven by the regulatory parties, but also influenced by a variety of non-governmental organizations. For the authors' purpose, the social aspect is defined as any societal contribution that may potentially effect the implementation of a performance based code, either as accelerators or decelerators.

The social factor that has been mentioned most is the interconnections of different countries in regards to their fire safety practices. The professionals in the fire protection field collaborate through international conference, project, and organizations and the outcome will usually influence more than one country. Sweden, for instance, has a fire safety guidance document comparable to *Code of Practice* in United Kingdom and *Design Guide* in New Zealand ( Bukowski, 1995). Similarly, the National Research Council of Canada established FiRECAM (Fire Risk Evaluation and Cost Assessment Model) based on the performance code model from Australia (Bukowski, 1995).

Since both Hong Kong and New York City have leading fire safety technology and research achievement in the world based on their low fatality number, they are one of the regions that are highly involved with any performance based code development trend. Hong Kong and New York City could have easily followed a foreign fire code, and made some modifications based on their own conditions. However, the two cities are both very independent in regards to their fire safety policies. New York City has a unique fire code that is different than the fire code of New York State (Bloomberg, Scoppetta, Cassano, Bazel, & Hansen, 2008). Hong Kong's Department of Building Service addressed the argument that copying oversea fire codes is not an appropriate approach because every country has their unique characteristics (Chow, 2002). In addition, W. K Chow also mentioned that different countries may have different levels of fire safety education to their citizens, therefore it is hard to evaluate the human response to fire in different countries (Chow, 2002). In 2003 there was a code revision project that reviewed New York City's current fire codes versus the International Fire Code (Cassano, et.al, 2010). Because of the 9/11/01 World Trade Center tragedy New York City felt that it needed to change something. The code was not necessarily bad, and the incident probably could not have been avoided if the code was better. However, there was a feeling that something had to be done. It took five years of research, deliberation, and comparison in order for New York City to enact the New York City Fire Code in 2008.

Besides international connections, non-governmental organizations in a country or region will also impact the performance based code implementation. In Australia, the Fire Code Reform Centre Ltd. (FCRC) is a non-profit organization that helped with the reformation of Building Code of Australia (BCA) ( Bukowski, 1995). In the United States, there are professional engineering societies that have been supporting the fire safety industry for decades. The SFPE and the American Society of Civil Engineers (ASCE) collaboratively produced a structural fire safety calculation as an alternative engineering method standard ( Bukowski, 1995). In Hong Kong, they established a Fire Safety Ambassador Club in 1988 to educate the public (especially younger generations) on basic fire safety knowledge (Lo, 2008).

The adjustment from a prescriptive code to a performance based fire code may create inconvenience or financial loss to certain industries. Without doubt, a performance based code offers a lot more design flexibility. However, that requires the contractors and designers to have more fire safety knowledge for the non-prescriptive features (Begley, 2004). Currently, some building material contractors have advantages in the market because their material is

Underwriters Laboratory (UL) rated. Those advantages may not be so appealing once a more flexible fire code is adopted. Besides the contractors, the insurance company will also be influenced by the code adjustment. Compared with a prescriptive code, a performance based code focus less on property protection (Bukowski, 1995).

### 2.6.1 Social Aspect as the Sustainability of a Building

In recent years, the building industry is trying to reach a more sustainable approach to building construction. This trend may also have a social impact on building regulations, especially for fire safety. For instance, one common approach to achieve the high energy efficient goal is to use well insulated materials, which is a potential hazard in case of fire safety because some insulating material also has a high combustible characteristic (Hamans, 18-10-2012). One example of this situation is the solar decathlon house designed by BE-MA-NY team for the 2013 Solar Decathlon China competition.

The house utilized a composite material as its primary structure in order to simplify the construction procedure and achieves a higher energy performance. However, the innovative material was not tested in accordance with the prescriptive code, so an alternative approach had to be taken. In addition, due to the combustibility of the material, treatment was required to meet alternative test requirements, which in this case involved application of an intumescent paint to provide resistance to flame spread and smoke production.

Similarly, modern construction usually focuses on improving air tightness by using mechanical ventilation systems. This will allow smoke and toxic gas exhaustion from the building in case of a fire. According to data from European Sustainable Consulting, 8 out of 10 fatalities in regards to fire accident result from smoke and toxic gasses (Hamans, 18-10-2012). Therefore, more attention should be drawn to this issue.

# Section 3: Methodology

## 3.1 Research Review

As reflected in the literature review above, several factors repeatedly appeared with respect to successful adoption of performance-based building and fire codes, specifically, issues associated with education, technology, history, social support and regulatory systems. Given this set of factors, the next step taken was to reconsider the literature reviewed to try and define set of discrete factors under each major issue, which could contribute to the acceleration or deceleration of performance code adoption in Hong Kong or New York City. It was beneficial that the original scope of the project looked at building codes in both Hong Kong and New York City, with the focus on high rises building, because it gave a clearer sense of how building code are influencing the building industry with data, examples, and analysis. Being able to go into the revised project statement with an understanding of what the codes were, and how they worked in each country was very beneficial. The initial research also helped up narrow down the best places to look for accurate and relevant information.

After an adequate amount of documents were reviewed, a way was needed to organize all the information obtained. The initial step to accomplish this was to identify sub-topics (factors) under each major issue (topic) and place that information in a table. The next step was to determine how to compare the factors with respect to their relevancy in accelerating or decelerating performance code adoption in Hong Kong and New York City. It was ultimately decided to apply a decision support tool to assist in this ranking, and the tool SuperDecision, based on the Analytical Hierarchy Process (AHP), was selected. The factors were then ranked by the authors for their relevancy in accelerating or decelerating performance code adoption in

Hong Kong and New York City and in helping to identify whether a performance or prescriptive code was best for each city. The approach to development of factors and selection of the decision support tool is detailed below. The analysis of the factors, relative to Hong Kong and New York City, is provided under the Analysis section.

## 3.2 Factor Identification and Description

As noted above, once the top-level issues (topics) of education, history, social support, technology, and regulatory system were identified as key issues related to adoption of performance codes or remaining with prescriptive, a secondary literature review was undertaken which focused on the amount of times these topics and various factors under these topics appeared in the literature. This was used as a measure of how important the various topics were. The initial option considered for organizing and ranking the relevancy of this information was through the use of a table. By constructing a table for each city we were able to see all the factors listed out rather than searching through sources for them. However, the table became unwieldy, and there was no structure to guide ranking. This ultimately led to the selection of the use of AHP and the SuperDecision software. A representation of the table can be found in Appendix 6. Discussion of AHP and the SuperDecision software follows in Sections 3.3 and 4.1 below. In creating the table, however, it was needed to create common definitions of the factors for use in the analysis. Descriptions of these factors are presented below.

The format used for presentation of the factors is a descriptive title (bold), followed by the main topic area under which it fits (CAPITALS), followed by a brief definition / description of what is meant. These factors titles and definitions are important as they are used in the relevancy ranking. The factors titles and definitions are provided as appropriate to the two focus cities, Hong Kong and New York City.

### 3.2.1 New York City

- **Amount of Research and Papers available:** *EDUCATION-Research and papers that have been created are what will be analyzed when looking into performance based fire code. It is necessary to make sure there has been enough research done, and papers written if a performance based fire code is to be implemented.*

- **Code Officials Outlook:** *REGULATORY- Code officials are very accustomed to using prescriptive fire code. Because of this it may be difficult to change to a performance based fire code for several reasons.*

- **Contractors' compatibility with prescriptive code:** *SOCIAL- Currently, contractors are set up to deal with prescriptive code much better than performance based code. Because of this if the contractors are taken into consideration prescriptive code may seem like the better option*

- **Effects of 9/11:** *HISTORY- As terrible as the events of September 11, 2001 were, investigations into the fires and collapses by NIST have brought forth some positive research and recommendations for performance-based codes and performance based design*

- **Existence of Effective Nonprofit Organizations:** *SOCIAL- In countries reviewed, like Australia, New Zealand and the USA, non-profit organizations help develop and facilitate implementation of performance based codes. If these non-profit organizations exist, then it would be easier to bring in performance based fire code.*

- **How Performance Based Codes Effect Fire Departments:** *REGULATORY- Performance based codes can create added protection of life to occupants and fire fighters.*

- **Insurance Companies benefits with prescriptive code:** *SOCIAL- Performance based codes do not necessarily address protection of property (varies by country), and this may not be appealing for insurance companies. Prescriptive code does deal with property protection (at least in USA, to some extent).*

- **Lack of Education of Code Officials:** *EDUCATION- Currently code officials work with a prescriptive fire code, and do not necessarily understand all of the engineering principles and mathematics of analysis and modeling used in support of a performance based design. If a performance based code was implemented code officials would have to be educated on fire protection engineering.*

- **Level of innovation in current building:** *TECHNOLOGY- Current buildings are generally more technologically advanced than previous. New technologically advanced construction is very difficult to design using prescriptive code. Hence, the use of performance based fire code would make things easier for innovative materials and systems.*

- **Quantity of Fire Labs Available for Testing and Research:** *TECHNOLOGY- Fire laboratory functions range from research of materials to testing of materials for code compliance for companies. With the implementation of performance based code, laboratories will be used quite often. If there are not enough laboratories it could be difficult to implement a performance-based code.*

- **Quantity of Universities with Fire Protection Engineering:** *EDUCATION-Universities with fire protection engineering are where many research and papers come from. Many countries have worked very closely with universities when implementing a performance-based code. Hence, there has to be enough universities working in related areas in order to successfully implement a performance based fire code.*

- **Regional/General System Outlook:** *REGULATORY- The regulatory system in the region (jurisdiction) where a performance code is desired will have to go through many steps in order to implement a performance based code. If a current prescriptive code results in a relatively safe environment, and industry is okay with the current situation, there may be little motivation for the introduction of performance-based code.*

- **Relationship with Performance Based Fire Code Countries:** *SOCIAL- If the city is able to have good relationships with other countries who have already implemented performance based code, then they may be able to get help and insight into the implementation. Also, the city can look into what others have done and benefit from lessons learned.*

- **Results from Incidents:** *HISTORY- Many code changes have happened from fires. There is a question of whether this constant investigation and modification to prescriptive* *codes will carry forward into the implementation and maintenance of performance based codes.*

### 3.2.2 Hong Kong

- **Amount of Research and Papers available:** *EDUCATION-Research and papers that have been created are what will be analyzed when looking into performance based fire code. It is necessary to make sure there has been enough research done, and papers written if a performance based fire code is to be implemented.*
- **Building department's outlook:** *REGULATORY-In Hong Kong, the building department consists of new building division, existing building division, and mandatory building inspection division. There was an indication that the Hong Kong building officials had considered that performance-based engineering might be used for modern complex buildings. However, they were still not fully comfortable in accepting the fire safety engineering design because of their limited knowledge, inadequate fire and evacuation prediction tools, and the unclear liability.*
- **Contractors' compatibility with prescriptive code:** *SOCIAL- Currently, contractors are set up to deal with prescriptive code much better than performance based code. Because of this if the contractors are taken into consideration prescriptive code may seem like the better option*
- **Effect from the Establishment of Hong Kong SAR:** *HISTORY- The establishment of Hong Kong SAR impacted the political and social structure in Hong Kong to a certain extent. It may also meant that Hong Kong's fire safety regulations were changed from the*

*previous British code in 1997.Once this change was made Hong Kong was very eager for change, and is currently very open minded.*

- **Existence of Effective Nonprofit Organizations:** *SOCIAL- In countries reviewed, like Australia, New Zealand and the USA, non-profit organizations help develop and facilitate implementation of performance based codes. If these non-profit organizations exist, then it would be easier to bring in performance based fire code.*

- **How Performance Based Codes Effect Fire Departments:** *REGULATORY- Performance based codes can create added protection of life to occupants and fire fighters.*

- **Insurance Companies benefits with prescriptive code:** *SOCIAL- Performance based codes do not necessarily address protection of property (varies by country), and this may not be appealing for insurance companies. Prescriptive code does deal with property protection.*
- **Lack of Education of Code Officials:** *EDUCATION- Currently code officials work with a prescriptive fire code, and do not necessarily understand all of the engineering principles and mathematics of analysis and modeling used in support of a performance based design. If a performance based code was implemented code officials would have to be educated on fire protection engineering.*

- **Level of innovation in current building:** *TECHNOLOGY- Current buildings are generally more technologically advanced than previous. New technologically advanced construction is very difficult to design using prescriptive code. Hence, the use of* *performance based fire code would make things easier for innovative materials and systems.*

- **Quantity of Fire Labs Available for Testing and Research:** *TECHNOLOGY- Fire laboratory functions range from research of materials to testing of materials for code compliance for companies. With the implementation of performance-based code, laboratories will be used quite often. If there are not enough laboratories it could be difficult to implement a performance-based code.*

- **Quantity of Universities with Fire Protection Engineering:** *EDUCATION-Universities with fire protection engineering are where many research and papers come from. Many countries have worked very closely with universities when implementing a performance-based code. Hence, there has to be enough universities working in related areas in order to successfully implement a performance based fire code.*

- **Regional/General System Outlook:** *REGULATORY- The regulatory system in the region (jurisdiction) where a performance code is desired will have to go through many steps in order to implement a performance based code. If a current prescriptive code results in a relatively safe environment, and industry is okay with the current situation, there may be little motivation for the introduction of performance-based code.*
- **Relationship with Performance Based Fire Code Countries:** *SOCIAL- If the city is able to have good relationships with other countries who have already implemented performance based code, and then they may be able to get help and insight into the implementation. Also, the city can look into what others have done and benefit from lessons learned.*

- **Results from Incidents:** *HISTORY- Many code changes have happened from fires. There is a question of whether this constant investigation and modification to prescriptive codes will carry forward into the implementation and maintenance of performance based codes.*

## 3.3 Approach to Assessing Relevancy of Factors and Relationship to Performance

Given the list of topic areas and sub factors, the next question is to find out how relevant the topics and sub factors are to the decision of performance over prescriptive code, and what is the best option for type of code for the cities considered. Because the outcome was decision based, a mathematical decision making process called Analytical Hierarchy Process (AHP) (Saaty, 1988) was applied to make sure the decision making process is logical and scientific.

When facing a simple decision making process, where there is only one factors that could dominate the decision outcome, it is easy to obtain the outcome. For example, if someone needs to decide which mobile device to get purely based on price, he can easily pick the model with the lowest price among all the options. However, the process will be much more complex in most decision making models in reality, since a lot of decisions are determined not only by one single factor. Sometimes, it is difficult to weigh the factors quantitatively as well.

The next step to undertake is to select a decision making tool that is able to assist in making the decision. The selection of a suitable tool is based on multiple factors such as the decision problem, the number and type of the criteria and so on. In this case, elementary methods such as “Pros and Cons Analysis”, “Maximum and Minimum Methods” are not appropriate since they are not computational to support multiple criteria categories(Fülöp, 2005). The decision-making problem of fire code implementation is a multi-attribute utility model, where the weights of the criteria can reveal the relative rank of the criteria. There are several method available to analyze a multi-attribute model: the Simple multi-attribute rating technique (SMART), which is the basic additive model; generalized means method, which introduced the decision matrix and generalized means to determine the ranking values; the Analytic Hierarchy Process (AHP), which adapt individual calculations of relative rank to a set of scores and weights(Fülöp, 2005).

AHP is a decision making method based on linear algebra mathematical thinking (Saaty, 1988). Thomas L. Saaty created the method in the 1970s and it has been widely applied in many fields for decision-making. A typical AHP model consists of objective, criteria, and alternatives. Sometimes, there will be sub-criteria in more complex models. A COBR (cost, opportunity, benefit and risk) model is also common in applications.

## 3.4 Building an AHP Model

There are five steps in building the AHP model (Fülöp, 2005):

1. **Determining the overall objective of the model**

   The first step of building the AHP model is to determine the overall goal/objective of the model. It is usually a goal of selecting the most suitable alternative based on the criteria listed. The goal has to be clear so that the rest of the model can be tied to the goal.

2. **Structuring elements such as criteria, sub-criteria, alternatives, etc.**

In an AHP model, the alternatives are all the possible output for the objective/goal, and the criteria are the factors that will determine the ranking of the alternatives. The criteria of AHP can be divided into two main categories: actual measurement (price, weight, speed, etc.) and subjective opinion (satisfaction, preferences, etc.). An example of a simple AHP model is shown in Figure 7.

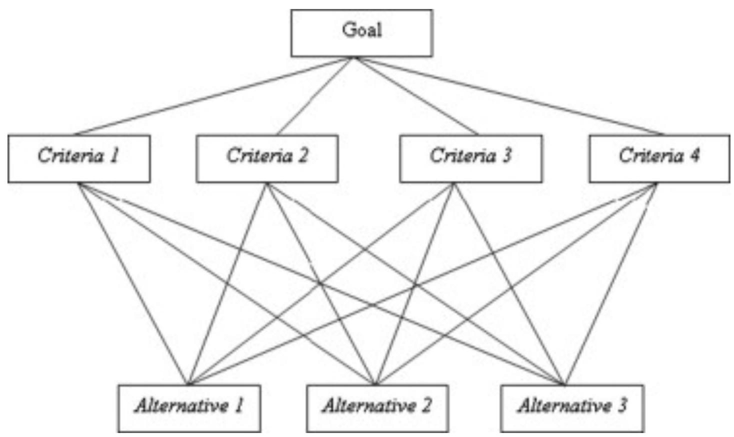



Figure 8: Simple AHP Model

3. **Making a pairwise comparison of elements in each group**

After building the structure of the model, the authors needed to conduct pairwise comparisons to weigh the importance among the criteria. There are five different ways to perform the pairwise comparison: graphical, in which you compare two criteria in a pie chart; verbal, in which the weight between two criteria is divided into five importance levels (extremely, very strongly, strongly, moderately, and equal); matrix and direct, in which outputs the matrix values among all the criteria already; and finally, questionnaire, in which two criteria will be compared from a scale one to ten. The questionnaire method is usually the preferred method because it is straightforward and it avoids the linear algebra calculation for the model. Analytic Hierarchy Process will then derive ratio scales from paired comparisons (BPMSG, 2010). It also tolerates some minor inconsistencies in judgment. After pairing comparisons, AHP will generate an output with the ratio scales of the alternatives and a consistency index based on Eigen vectors and Eigen values.

4. **Calculating weighting and consistency ratio**

   After the pairwise comparison, a weighting matrix can be calculated using the linear algebra method. The sum of the normal values of the alternatives should add up to 1. After that, the ideal values can be calculated by setting the alternative with the highest normal value to 1, and idealize the other alternatives by dividing each of their normal value by the highest normal value.

5. **Evaluating alternatives according to weighting**

   The alternatives will be ranked according to their ideal value. The alternative with an ideal value equals to one is the best option for the goal/objective.

## 3.4 Mathematical Theory of AHP

After finalizing the structure of the model, pairwise comparisons needed to be undertaken. This is done as follows (Fülöp, 2005). The first step is comparing different criteria with one another. A scale from one to ten is being used. One point stands for both criteria are of the same importance, and ten towards criteria A means that criteria A is 10 times more important (extremely important) than criteria B in the decision making of code implementation. The number of comparison can be determined by the formula $(n^2 - n)/2$ to complete the comparison between different criteria. The next step is to arrange the result in a matrix, which can be computed the normalized Eigen factors (in table 2, which is in section 4.2). Then the Eigen vectors of the matrix can be found from this the sum. After obtaining the sum of the columns, the first normalized principal Eigen vector $x_1$ can be calculated. Next step is to square the normalized matrix N and calculate the next iteration of Eigen vector until the difference of x is negligible.

### 3.5 AHP Software – SuperDecision

The hand calculation of AHP method is extremely time consuming even for a simple decision model. Therefore, AHP software needed to be selected as a tool to conduct the matrix calculation process. The software that is currently available can be put into three categories: functional but not free, function and free, or simply and free. One example of software that was functional but not free was MakeItRational. This met all of our needs, but was not available for free. Examples of this software can be seen in Figure 8 and 9. The software chosen by the authors was both functional and free. It was titled SuperDecisions, and can be seen in various figures throughout this report. One example of how it was used by the authors can be seen in Appendix 5.

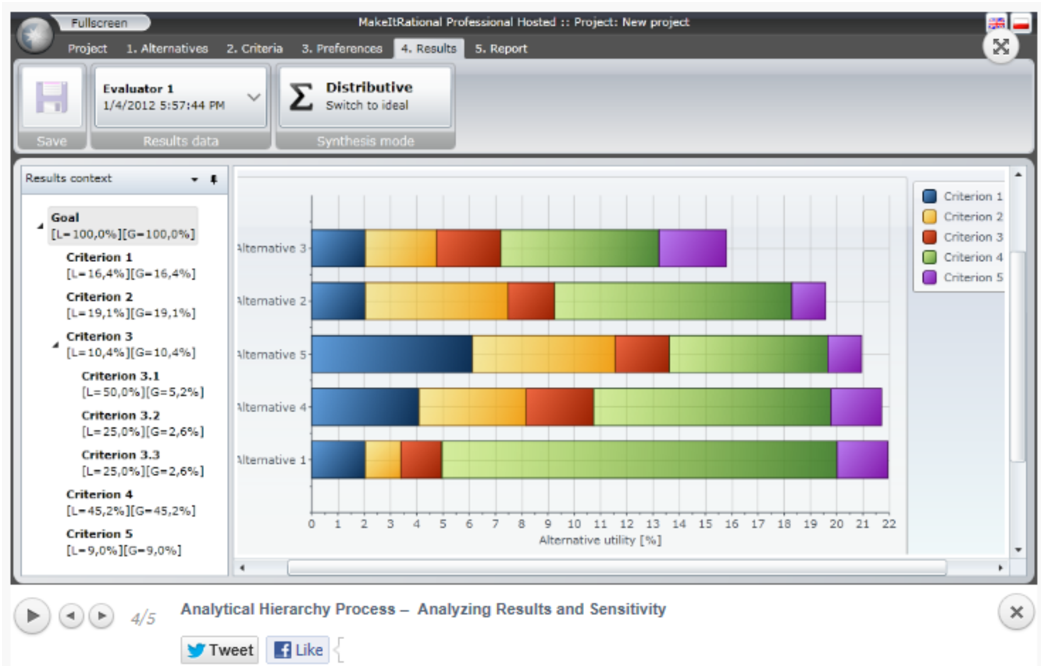



Figure 9: MakeItRational AHP Software graphs

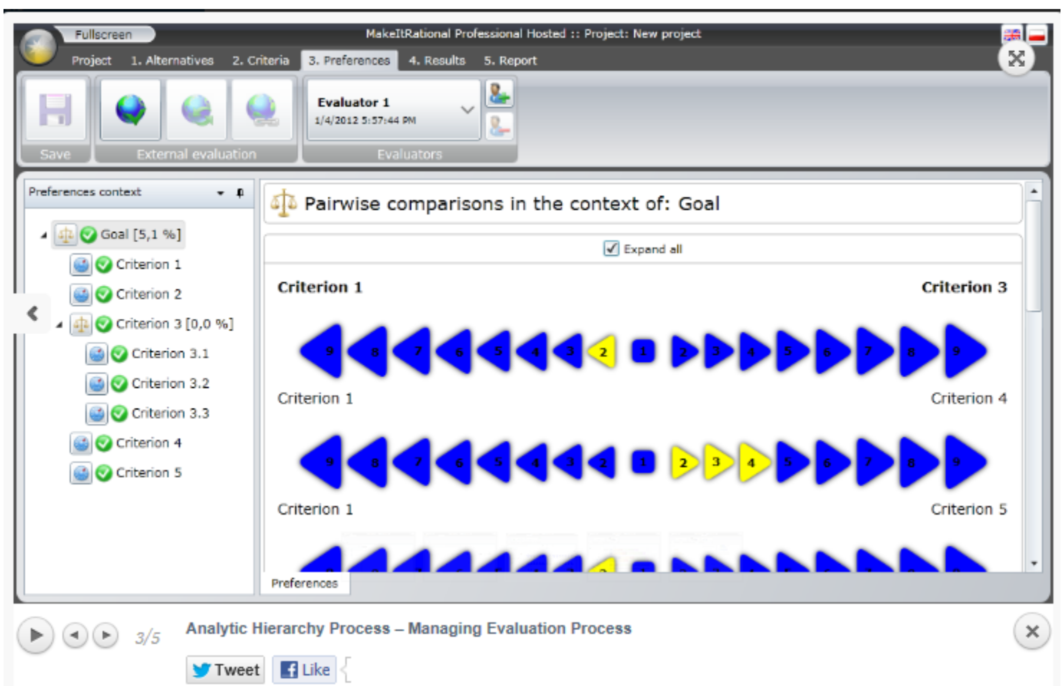



Figure 10: MakeItRational Pairwise Comparison

| Product | Version | Price | | | |
|---|---|---|---|---|---|
| | | 1 month | 3 months (10% discount) | 6 months (20% discount) | 12 months (40% discount) |
| **MakeItRational Basic** (1 project, 2 evaluators) | Online | $17 | $46 | $82 | $122 |
| **MakeItRational Team** (3 projects, 10 evaluators) | Online | $37 | $100 | $178 | $266 |
| **MakeItRational Professional** (5 projects, 25 evaluators) | Online | $57 | $154 | $274 | $410 |
| **MakeItRational Desktop** (Unlimited projects, 40 evaluators) | Desktop | $997 (one time fee) | | | |

Figure 11: MakeItRational Cost Problem

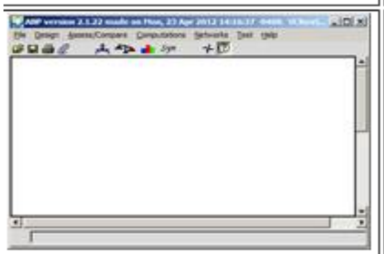
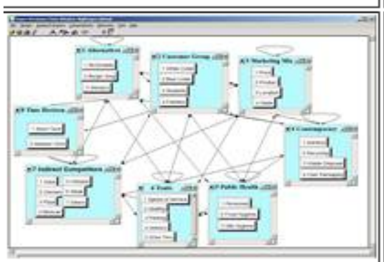
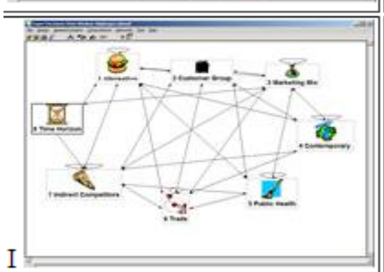
| Thumbnails (click to enlarge) | Description |
|---|---|
|  | This is the SuperDecisions software icon that will appear on your desktop after you install it. Double-click to start the program. |
|  | This is what the program looks like just after starting the software on Windows. To build a hierarchy or a network you must *Design* clusters, nodes and links. |
|  | This is the Big_Burger sample model for estimating market share using "soft" factors running on Windows. It is a single network with clusters, nodes and connections appearing in a window that is the main screen view.<br>Inner dependent links are indicated by loops on clusters.<br>As manufacturing goes digital, it will change out of all recognition, says Paul Markillie. And some of the business of making things will return to rich countries |
|  | This is the Big_Burger sample model with all of the clusters iconized. |
|  | This is a partial view of the limit matrix from the Big_Burger model. |

Figure 12: SuperDecisions software example

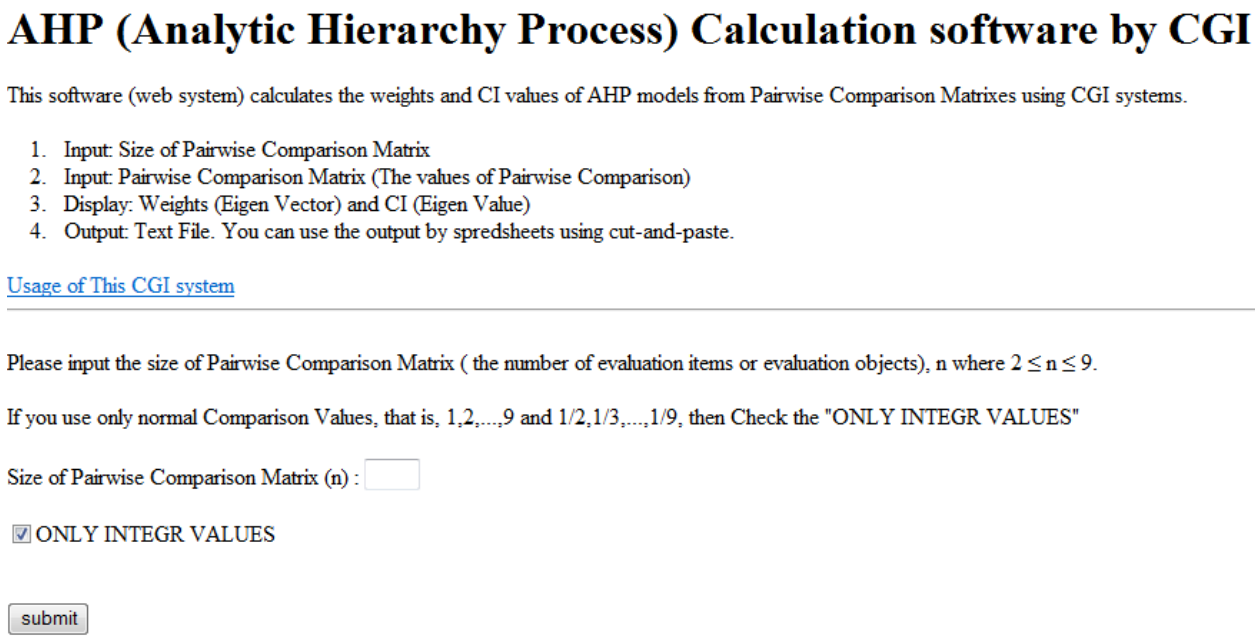



Figure 13: Example of how SuperDecision is not very user friendly

The SuperDecision is decision making software based on the Analytic Hierarchy Process (AHP) theory (Saaty, 1988) created by Thomas Saaty. In SuperDecision software, the priorities or decision outcomes are calculated based on the fundamental mathematical theories of AHP through a pairwise comparison interface. The SuperDecision software is capable for inconsistency detection, sensitivity analysis, and making the decision of the alternatives. The SuperDecision software was selected as the software to analyze whether performance code or prescriptive code is a better option because:

1. It gives a relative complete AHP analysis, both numerically and graphically.

2. It can be obtained for free from the Internet.

3. It has a comprehensive tutorial and a decision-making model library, which allows beginners to learn the software operation faster.

### 3.6 Example Model-Choosing a Vacation Spot

Here is a simple model to better illustrate the methodology of AHP the application of SuperDecision Software that was discussed from above. The model is about selecting the best vacation place based on “activity, nightlife, sightseeing, and cost”. The model is referenced from the SuperDecision Tutorial Document and it can be accessed under through the link presented (http://www.superdecisions.com/category/support/tutorials/tutorials-in-world/). The goal of the model is to select the best vacation location among all the destinations available. To put this goal into SuperDecision software, to the user goes to “Design”→ “Cluster”, select “new” to get the dialogue window (Figure 13). Afterwards, one types in “Goal” in the name box. Once the “Goal” cluster is finished, the user clicks on “create another” on the left bottom side to create the criteria cluster. Finally, create the “Alternative” cluster is where the user can put in all the different alternative cities that are being considered. The layout should look like Figure 14 after proper resizing and rearranging.

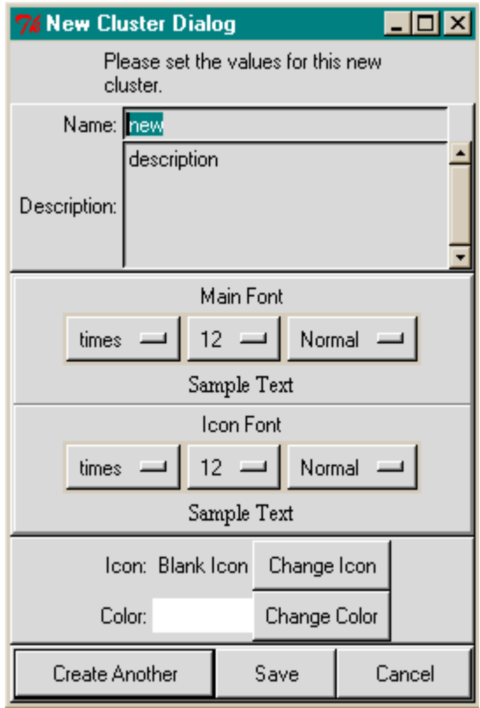



Figure 14: SuperDecisions Cluster Dialog Window

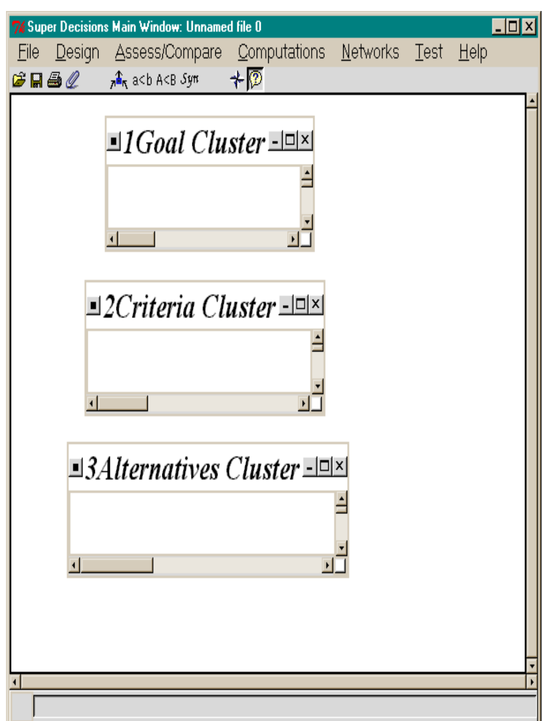



Figure 15: Example of Simple AHP Using SuperDecision

Next the user needs to create different elements inside each cluster. Again the user goes to “Design”, and select “Node” → “new”. As the dialogue box instruction directs, the user will choose a cluster in which to add the element. Starting from the top of the model, the user should select “Goal” cluster first. Type “Goal” once again in the name bar, and then type in the details of the goal in the description box. The font and color of the node can be changed according to personal preference. Then insert the elements into the “criteria” and alternative” clusters following the same procedure. The completed model should look similar to Figure 15.

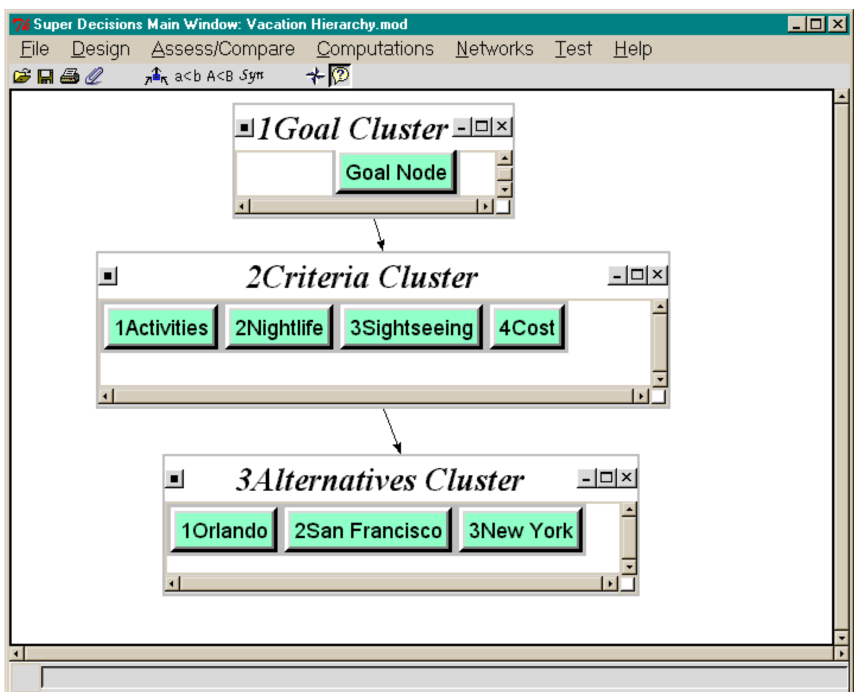



Figure 16: Simple Vacation Example

When all the elements are in place, the user needs to connect them accordingly. First, the user should find the “Making Connections” icon () and click it so that it is active. The user should then press <shift> key and left click on one of the nodes from an upper cluster, then connect all of the elements from the lower cluster to it. Once the model is completed, the user should go to "Compare"→ "Pairwise Comparison" and complete the questionnaire based on the level of importance for all the criteria (Figure 16). After the comparison is completed, a matrix analysis will be calculated automatically, along with a full report of rankings between alternatives.

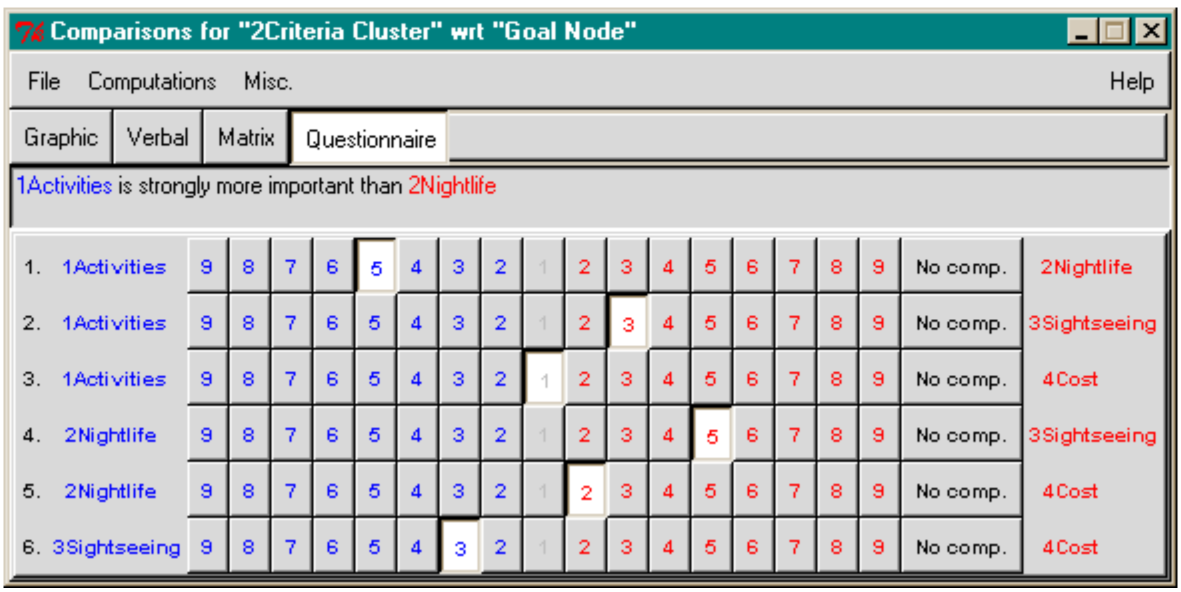



Figure 17: Vacation Example Pairwise Comparison

## Section 4: Analysis

This section describes the application of AHP, using the SuperDecision software, to ranking the relevance of the topic areas (education, history, technology, social, and regulatory system) and sub factors identified in Section 3 above to the question of whether moving towards a performance based code or staying with a prescriptive based code is best for Hong Kong and New York City. This assessment is based on the literature review and interpretation of importance of the topics and sub factors by the authors.

### 4.1 AHP Model of Performance Based Fire Code Implementation

Following the five steps discussed in the methodology section, one can structure the decision model for most appropriate type of code for Hong Kong and New York City accordingly. The major challenge of structuring this model is that there are both accelerators and decelerators to influence the decision making, and mathematically, it is hard to evaluate both in one single model to get an accurate output. Since the expectation of the output is to understand the ranking of both accelerators and decelerators for performance based fire code implementation, and to determine whether performance based code is a better option for the case study cities or not, three separated models were made for both cities (6 models total): the accelerator model, the decelerator model, and the decision making model. The three models share the same structure but the pairwise comparisons are different in the three models. Noticing that in the decision-making model, the alternatives are named as "criteria" and under the new alternative cluster, there are "performance based code" and "prescriptive code". As a result, the output will be a comparison result between performance code and prescriptive code instead.

The objective of the accelerator model is to determine which factor is the most influential accelerator to the implementation of a performance based fire code. The criteria are education, technology, history, social, and regulatory impact. Under the criteria, there are alternatives that vary according to the cities being investigated. For instance, the 9/11 Incident was under history criteria in New York City because the city government and fire department reevaluated and modified their code after the incident; while the sovereignty of Hong Kong transforming from British colonial to Special Administrative Region of China was listed under its history criteria since it has an impact on the building fire code decision makings. The detail structure of both models can be found in Figure 17 and 18.

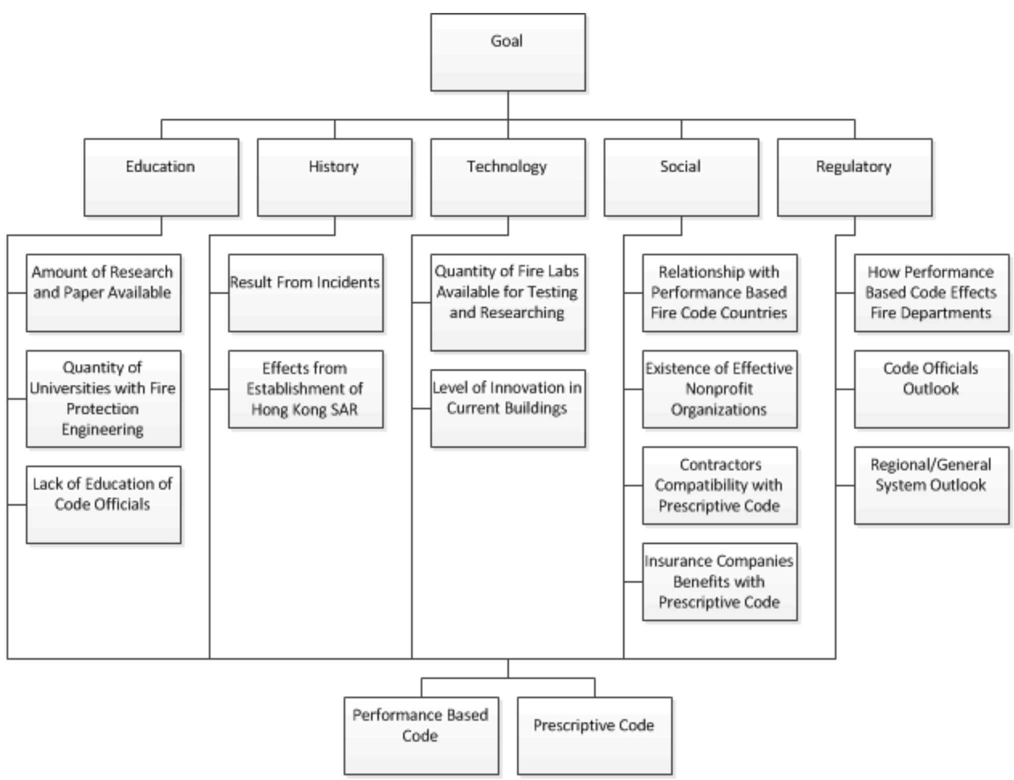



Figure 18: Hong Kong AHP

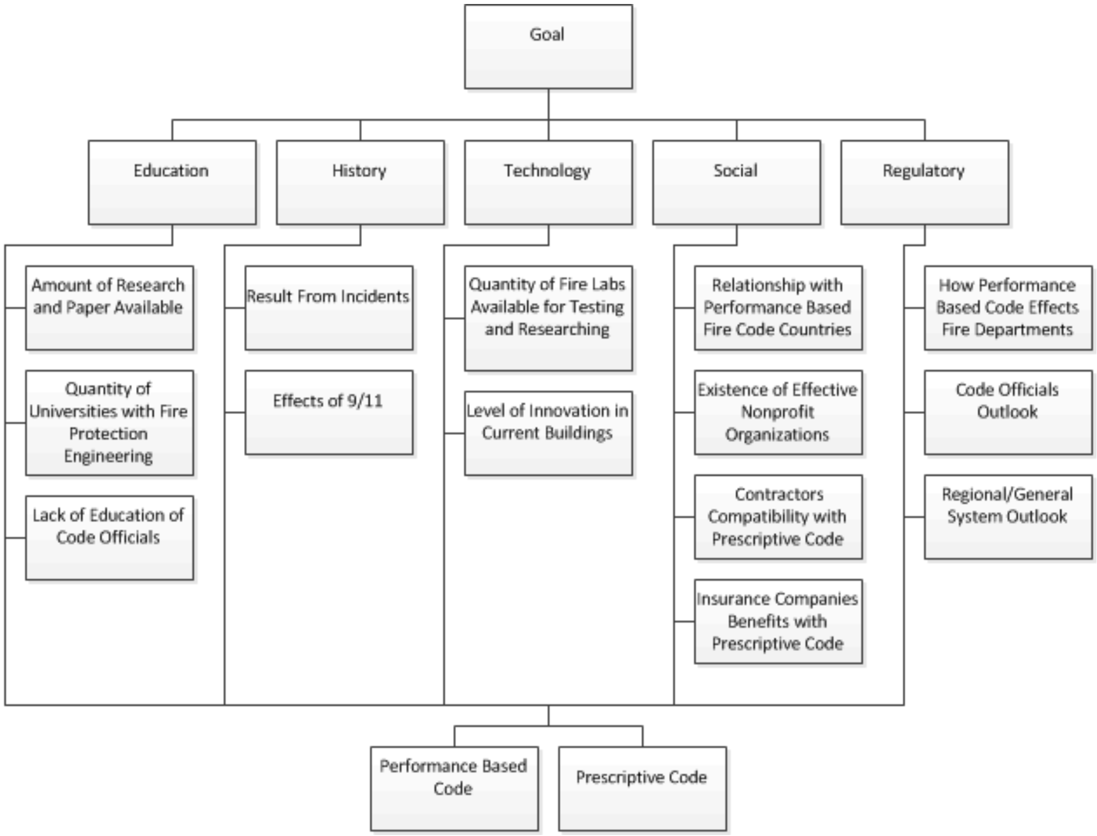



Figure 19: New York City AHP

In the content of making a decision between performance and prescriptive code, there are nine factors in five different categories that are related to the decision making, as outlined above. In order to achieve the final outcome, it is essential to rank the nine factors from "the most important factor" to "the least important factor" in terms of relevancy to the decision. Because there were both upper level factors and sub factors within each upper level factor this was not easy. An approach to rank and assess importance or relevancy of the factors to the problem is essential. Preferably, the approach would be a mathematical approach that is able to solve all the complexity.

“Making a decision implies that there are alternative choices to be considered, and in such a case we want not only to identify as many of these alternatives as possible but to choose the one that best fits with our goals, objectives, desires, values, and so on” (Harris, 1980). During the investigation of this particular project, the goal is to determine whether New York City and Hong Kong should implement the performance-based code or not. The criteria were also created and categorized into five sets because grouping the criteria’s into different sets will help calculate each of their weights (Fülöp, 2005).

In the accelerator model, the criteria were weighed in regards to which criteria is more of an accelerator for the performance based code implementation. For example, between education and history, history is slightly more of an accelerator for the implementation of performance based because the alternatives under history accelerate the code transition towards performance more compared to the alternatives under education. Similarly, the weighting of all the alternatives under each criterion is determined by how much it accelerates the performance based code implementation. This same procedure can be taken and applied to the decelerator model. However instead, the goal is what factor is the largest decelerator of the implementation of performance based fire code.

The third model is slightly different than the accelerator and decelerator models. Instead of trying to achieve a relevancy as a result, the goal of the decision model is to get a definitive answer of whether or not implementing performance-based code is the best option. Adding another cluster to the model that will have two choices, prescriptive and performance does this. The reason one of the choices is prescriptive is because if a performance based code is not adopted then the city will retain their original prescriptive code.

The reason for having two relevancy models, opposed to jumping into one decision making model is to verify that the factors that appear as the largest decelerators are also the factors that appear as the lowest accelerators. This was important because the output of the accelerator/decelerator models is used as the input of the decision making model. Because the accelerator and decelerator models were opposites it made this possible. By doing this an answer can be obtained with minimal user at this stage.

## 4.2 Mathematical Theory

Basic concept of mathematical application of AHP was discussed in previous methodology section. Thus, the purpose of this section is only to demonstrate the mathematical theory applied particularly in the building code decision making scenario. When comparing between the importance of education and history in regards to accelerating the performance based code implementation in Hong Kong, a scale from one to ten is being used. For example, when comparing between education and history criteria, one point stands for both criteria are of the same importance, and 10 towards education means that education is 10 times more important (extremely important) than history in the decision making of code implementation. The number of comparison, in this particular case, is 10 $(5^2 - 5/2 = 10)$, which means 10 comparison is required in order to complete the comparison between different criteria. The results of the ten comparisons for Hong Kong are listed in Table 1. The next step is to arrange the result in a matrix, which can be computed the normalized Eigen factors (Table 2). Then the Eigen vectors of the matrix can be found from this the sum. After obtaining the sum of the columns, the first normalized principal Eigen vector $x_1$ can be calculated. Next step is to square the normalized matrix N and calculate the next iteration of Eigen vector until the difference of x is negligible.

Table 1: Example Pairwise Comparison of Hong Kong AHP

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Education | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | **2** | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | History |
| Education | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | **1** | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Regulatory |
| Education | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | **3** | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Social |
| Education | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | **7** | 8 | 9 | 10 | Technology |
| History | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | **1** | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Regulatory |
| History | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | **2** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Social |
| History | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | **7** | 8 | 9 | 10 | Technology |
| Regulatory | 10 | 9 | 8 | 7 | 6 | 5 | **4** | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Social |
| Regulatory | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | **6** | 7 | 8 | 9 | 10 | Technology |
| Social | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | **6** | 7 | 8 | 9 | 10 | Technology |

Table 2: Table in Matrix Form

| | education | Technology | history | social | regulatory |
|---|---|---|---|---|---|
| education | 1 | 1/7 | 1/2 | 1/3 | 1 |
| technology | 7 | 1 | 7 | 4 | 6 |
| history | 2 | 1/7 | 1 | 2 | 1 |
| social | 3 | 1/6 | 1/2 | 1 | ¼ |
| regulatory | 1 | 1/6 | 1 | 4 | 1 |

$$\begin{bmatrix} 1 & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21}^{-1} & 1 & a_{23} & a_{24} & a_{25} \\ a_{31}^{-1} & a_{32}^{-1} & 1 & a_{34} & a_{35} \\ a_{41}^{-1} & a_{42}^{-1} & a_{43}^{-1} & 1 & a_{45} \\ a_{51}^{-1} & a_{52}^{-1} & a_{53}^{-1} & a_{54}^{-1} & 1 \end{bmatrix}$$

$$[S_{c1} \quad S_{c2} \quad S_{c3} \quad S_{c4} \quad S_{c5}]$$

$$|N| = \begin{bmatrix} \frac{1}{S_{c1}} & \frac{a_{12}}{S_{c2}} & \frac{a_{13}}{S_{c3}} \\ \frac{a_{12}^{-1}}{S_{c1}} & \frac{1}{S_{c2}} & \frac{a_{23}}{S_{c3}} \\ \frac{a_{13}^{-1}}{S_{c1}} & \frac{a_{23}^{-1}}{S_{c2}} & \frac{1}{S_{c3}} \end{bmatrix}$$

$$X_1 = \begin{vmatrix} \Sigma \frac{row1}{n} \\ \Sigma \frac{row2}{n} \\ \Sigma \frac{row3}{n} \end{vmatrix}$$

$$X_2 = N^2$$

The same matrix method is applied to get the importance ranking of those alternatives as accelerators for code implementation. The final percentage output of each alternative is equal to the criteria ratio multiplied by the sub-criteria ratio from the normalized Eigen factors. The cost influence was not included in the model, but it allows us to do a cost-benefit analysis for the model if necessary.

## 4.3 Alternative Analysis

There are fifteen alternatives in total that are related to the fire safety code decision-making. Fourteen of them are the same between Hong Kong and New York City, while Hong

Kong has "Effect from the Establishment of Hong Kong SAR" and New York City has "Effect of 9.11" as their own factors.

In order to get a thorough understanding of the ranking result in both accelerator and decelerator models, four bar charts are created in order to compare rankings between:

1. Hong Kong Accelerators vs. New York City Accelerators
2. Hong Kong Decelerators vs. New York City Decelerators
3. Hong Kong Accelerators vs. Hong Kong Decelerators
4. New York City Accelerators vs. New York City Decelerators

Notice that the higher the rank is, the smaller the numerical value on the bar chart will be. For example, "Level of innovation in current building" is the largest accelerator, and it has the shortest bar in the bar chart below.

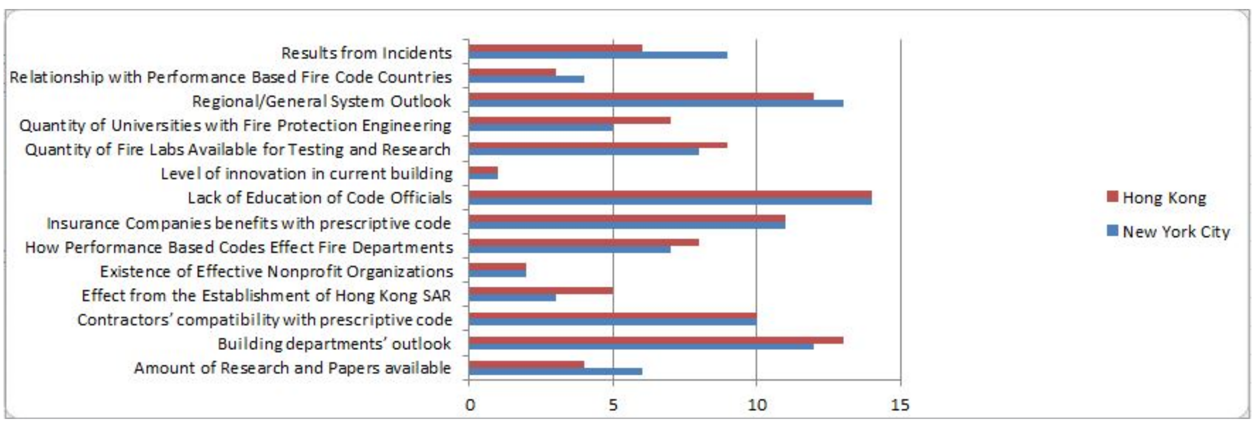



Figure 20: Accelerators in Hong Kong and New York City

Figure 19 shows the ranking of accelerators in Hong Kong and New York City. The same alternative commonly has similar ranking with a plus/minus two margin of difference. This shows good agreement of the factors for each city, based on data used by the modelers.

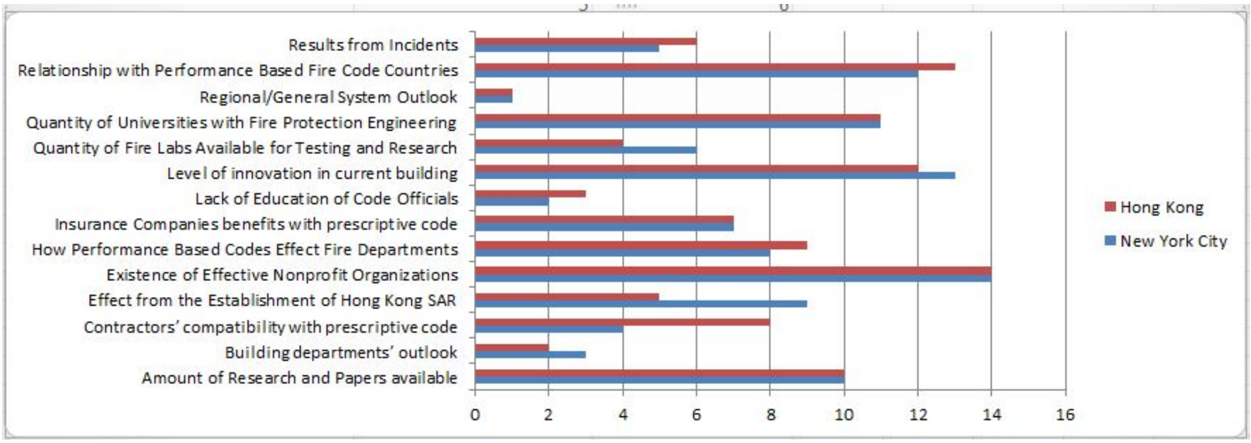



Figure 21: Decelerators in Hong Kong and New York City

Figure 20 shows the ranking of decelerators in Hong Kong and New York City. Similar to the accelerator chart, the same alternative also has similar ranking with a plus/minus two margin of difference. Comparing with the accelerators chart, the difference between the two cities is less significant. Again, this shows good agreement of the factors for each city, based on data used by the modelers.

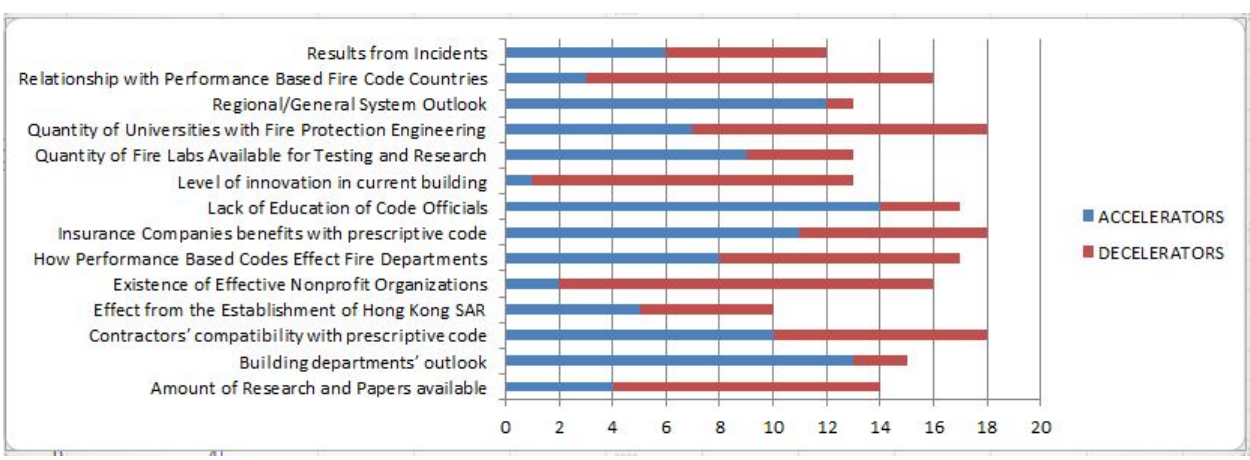



Figure 22: Hong Kong Accelerators vs. Decelerators

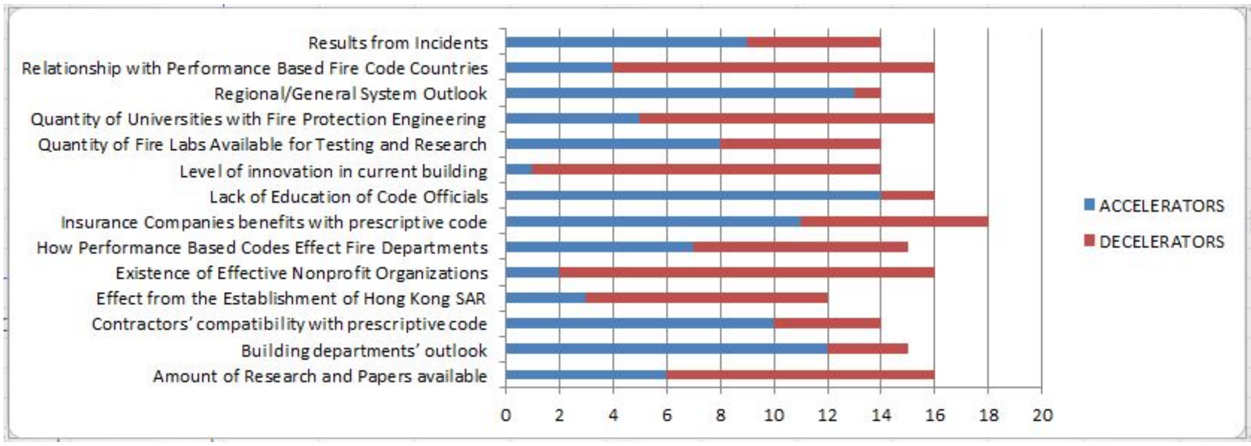



Figure 23: New York City Accelerators vs. Decelerators

Figure 21 and Figure 22 show the summation of accelerators and decelerators in each city. The value of the summations should add up to approximately fifteen, because usually for a certain alternative, the more it acts as an accelerator, the less it will act as a decelerator. These figure show that the decelerators and accelerators are approximately opposites. This allowed the authors to take the results from the accelerator or decelerator models and use them as the input to the decisions model (Appendix 5).

## 4.4 Sensitivity Analysis

A sensitivity analysis is to check the sensitivity of the final decisions in regards to minor changes in judgment (Al-Harbi, 2001). The sensitivity analysis offers a graphical interpretation of the ranking of the alternatives correspondent to the increasing or decreasing of the criteria's weights (Chang, Wu, Lin, & Chen, 2007). One reason of conducting a sensitivity analysis is to reflect how the result of the alternative will change based on different outlooks on the ranking of the criteria, since the weights are usually highly subjective conclusions (Chang et al., 2007). In general, the output is not general considered overly sensitive to an input parameter if the change in the output is in the same order of magnitude as the change in the input parameter (i.e., if the input parameter changes by 10% and the output changes by 10%, the output is not overly sensitive to the input parameter). Since sensitivity analysis demonstrates the stability of the rankings, it can also be used as a tool to check if there were any incorrect or illogical rankings (Chang et al., 2007): when the rankings are exceedingly sensitive to minor changes in the weights, a careful review of the rankings is recommended.

### 4.4.1 Overview of Sensitivity Analysis in SuperDecision Software

The SuperDecision software includes a feature to assess the sensitivity of decision criteria to the outcome. The following example from the SuperDecision tutorial is used to demonstrate how this works (Saaty, 1988).  In the decision making of choosing the best traveling destination example illustrated above, the result is depends on criteria of activity, nightlife, sightseeing, and cost, all four combined. It is obvious that the decision will be different between the case in which all the four criteria are equally important (each of them is 25% in a pie chart), and the case where price is the lead criteria (ex. price equals to 90% in a pie chart). Then there comes the question: how does decision outcome change in relation to the criteria's percentage? To solve this problem, the AHP method provides a graphical demonstration of the sensitivity.

The sensitivity analysis in SuperDecision addresses how the outcomes of the alternatives change in regards to a certain criteria's percentage of importance. The first step of the sensitivity analysis is to determine which criterion needed to be analyzed. It is noticeable that one sensitivity analysis can only investigate one criterion. For example, the user cannot conduct the sensitivity analysis of both "price" and "sightseeing" in the traveling model at the same time.

Another factor about the sensitivity analysis is the value and interval on the on the graph. The graph of sensitivity analysis consists of two values: importance of the criterion and priority of all the alternatives. The importance of the criterion is placed on the x-axis while the priority of the alternatives on the y-axis. The value of the importance of the criterion is presented as a numerical value that ranges from 0 to 1. The total ratio of different alternatives should also add up to 1. Figure 23 demonstrates the layout of a typical sensitivity analysis graph.

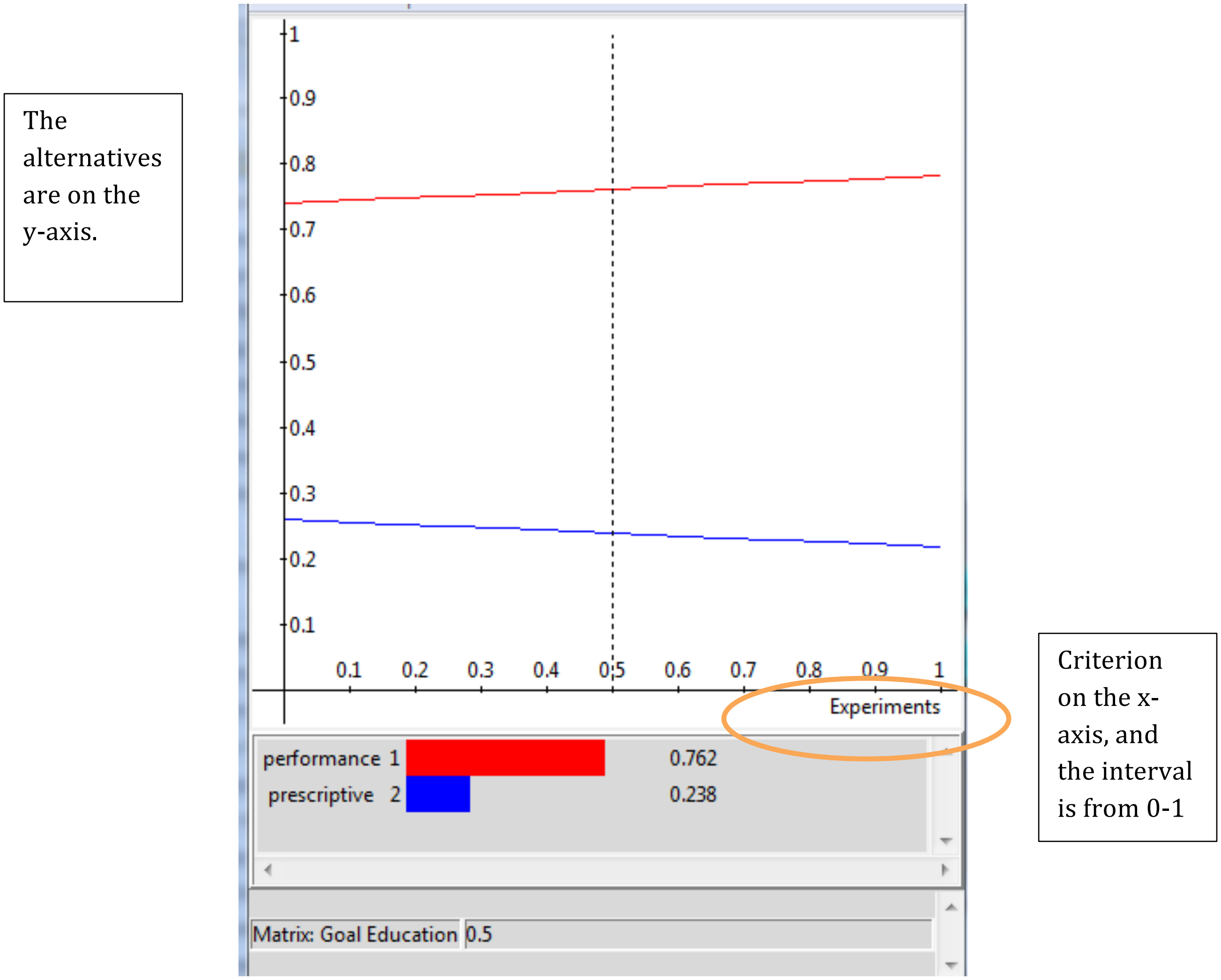



Figure 24: Typical Sensitivity Analysis Graph

The SuperDecision software is installed with the sensitivity analysis function. This paragraph will discuss the programming of a sensitivity analysis in SuperDecision software. First, go to the [computation] tab and choose [sensitivity] from the drawdown list. In the [sensitivity] pop-out window, choose [edit] -> [independent variable] to program the certain criterion that you want to analyze; Then click on [new] on the right side to create a new analysis. After the second pop-out window-[new parameter] appears (as illustrated in Figure 24), set the parameter type to “SuperMatrix” and Wrt Node to “Goal”, then pick one criterion from the model to analyze.

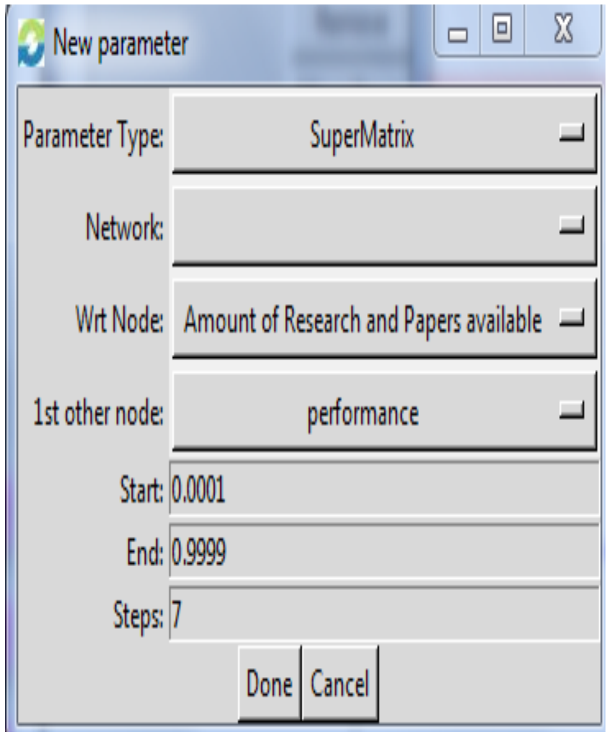



Figure 25: New Parameter Window

# Section 5: Results

The SuperDecision software will generate computations and results based on the model structure and ranking result. The computational result of fire safety code will be demonstrated in several different formats in order to give a comprehensive understanding of the outcome.

## 5.1 Un-weighted Super Matrix

The un-weighted super matrix is a matrix computational result that includes all the local priority vectors that have been calculated from the model. Traditional linear algebra calculation is replaced with such matrix computation by the software. The result of criteria cluster is demonstrated in figures 25 and 26 as example outcomes.

| Cluster Node Labels | | 1Goals | alternatives | | Criteria | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Goal | performance | prescriptive | Education | History | Regulatory | Social | Technology |
| 1Goals | Goal | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| alternatives | performance | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| | prescriptive | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| Criteria | Education | 0.156060 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| | History | 0.178290 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| | Regulatory | 0.077796 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| | Social | 0.310142 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| | Technology | 0.277713 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

Figure 26: Hong Kong Un-weighted Super Matrix

| Cluster Node Labels | | 1Goals | alternatives | | Criteria | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Goal | performance | prescriptive | Education | History | Regulatory | Social | Technology |
| 1Goals | Goal | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| alternatives | performance | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| | prescriptive | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| Criteria | Education | 0.156060 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| | History | 0.178290 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| | Regulatory | 0.077796 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| | Social | 0.310142 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| | Technology | 0.277713 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

Figure 27: New York City Un-weighted Super Matrix

According to the result, social and technology weighs the majority among all the criteria, which means social and technology were ranked relatively higher during pairwise comparison. The outcome is reasonable since the decision model is made according to the accelerators of building code, and social and technology aspects act more as overall accelerators than others. The result of New York City and Hong Kong matrix are the same because the criteria ranking of code type decision between those two cities are the same.

### 5.2 Weighted Super Matrix

Weighted super matrix result is very similar to the un-weighted super matrix result. In fact, the only difference is that the weight among the entire cluster has been weighted so that each column is stochastic (meaning the sum of all the columns adds up to one). The result of weighted super matrix for Hong Kong and New York City in regards to the fire safety code decision model is exactly the same as the un-weighted matrix result. This is due to the fact that no cluster comparison has been conducted. The cluster comparison would not be necessary because the summation of the columns in the un-weighted model has already been one.

### 5.3 Cluster Matrix

The cluster matrix demonstrates how the cluster weighs in comparison with each other. In the fire code decision model, all the clusters are goal, alternatives (performance and prescriptive), criteria 1(education, social, technology, regulatory, history), and criteria 2 (different alternatives under the criteria 1). The result of the cluster matrix is shown in figure 27.

| Cluster Node Labels | 1Goals | Alternatives | Criteria | Criteria2 |
|---|---|---|---|---|
| 1Goals | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| Alternatives | 0.000000 | 0.000000 | 0.000000 | 1.000000 |
| Criteria | 1.000000 | 0.000000 | 0.000000 | 0.000000 |
| Criteria 2 | 0.000000 | 0.000000 | 1.000000 | 0.000000 |

Figure 28: Cluster Matrix for Code Type Decision

Basically, the result in the cluster matrix is summary of the result of the unweighted super matrix. For instance, the goal/criteria cell shows value one, which equals to the total of all the cells in the criteria cluster in the unweighted super matrix.

### 5.4 Priorities

The priority result shows the priorities all the alternatives in the model. The priority result of the fire code model is demonstrated in table 3.

Table 3: Priority Results

| Name | Normalized By Cluster | Limiting |
|---|---|---|
| Goal | **0** | 0 |
| PBC | **0.78464** | 0.261545 |
| Prescriptive Code | **0.21536** | 0.071788 |
| Education | **0.15606** | 0.05202 |
| History | **0.17829** | 0.05943 |
| Regulatory | **0.0778** | 0.025932 |
| Social | **0.31014** | 0.103381 |
| Technology | **0.27771** | 0.092571 |
| Amount of Research and Papers available | **0.05722** | 0.019073 |
| Code Officials Outlook | **0.0139** | 0.004632 |
| Contractors compatibility with prescriptive code | **0.02105** | 0.007016 |
| Effects of 9/11 | **0.14857** | 0.049525 |
| Existance of Effective Nonprofit Organizations | **0.16341** | 0.054469 |
| How Performance Based Codes Effect Fire Departments | **0.05515** | 0.018382 |
| Insurance Companies benefits with prescriptive code | **0.01447** | 0.004823 |
| Lack of Education of Code Officials | **0.00801** | 0.00267 |
| Level of innovation in current building | **0.243** | 0.081 |
| Quantity of Fire Labs Available for Testing and Research | **0.03471** | 0.011571 |

| | | |
|---|---|---|
| Quantity of Universities with Fire Protection Engineering | **0.09083** | 0.030277 |
| Regional/General System Outlook | **0.00875** | 0.002918 |
| Relationship with Performance Based Fire Code Countries | **0.11122** | 0.037073 |
| Results from Incidents | **0.02971** | 0.009905 |
| Total | **3** | 1.00 |

The data under the "Limiting" column is the same result calculated from the limit matrix. The limit matrix is the matrix in which all the columns have the same values. This is achieved by raising the weighted super matrix to powers until it stabilized. The normalized by cluster values are attained by normalizing the priorities in the cells in order to get a summation of one. Since there are three different clusters ("alternative", "criteria 1", and "criteria 2"), the total of the normalized value equals to three.

## 5.5 Synthesize

The synthesize computation provides the priority vector for the alternatives in the model. It is the final analysis step towards a completed Analytical Hierarchy Process. Figure 28 and 29 give the result of synthesized computation of fire code selection. The raw value is the simple summation of the alternatives. The Ideal value is the value that has converged the highest alternative to one. In this case specifically, the ideal value of performance-based code is equal to one in both Hong Kong and New York City models. The normalized value is the value that normalized the alternative output so that the total will add up to one.

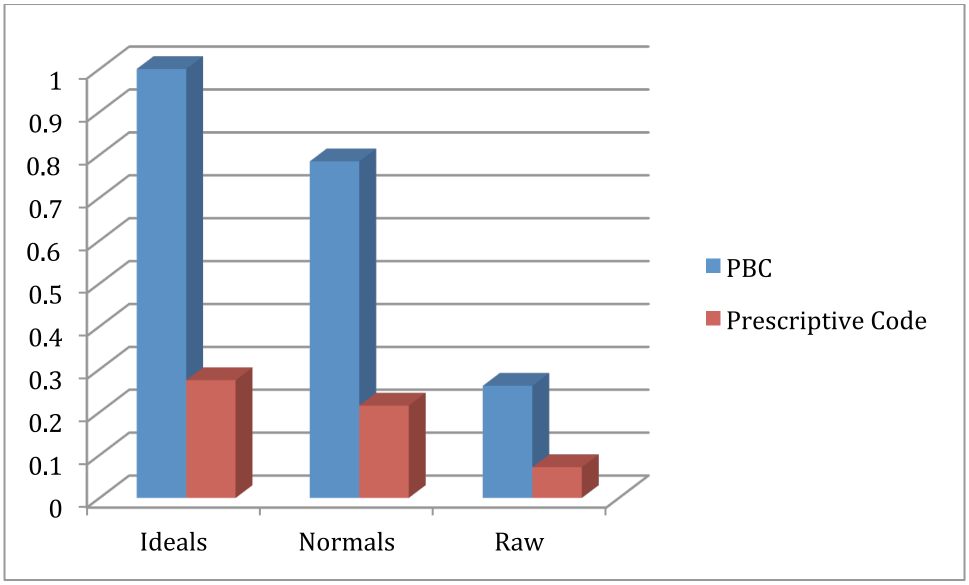



Figure 29 New York City Synthesized Result

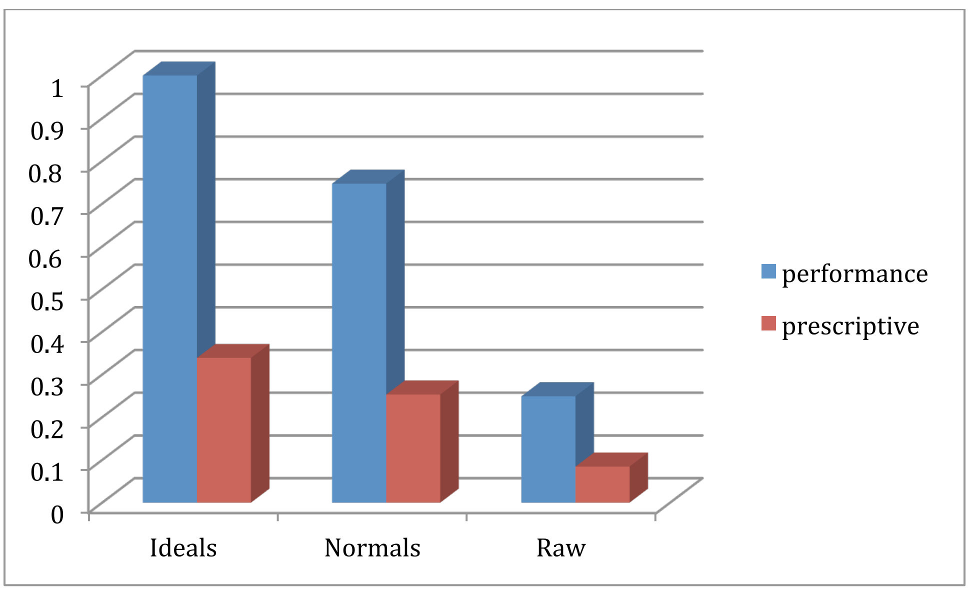



Figure 30 Hong Kong Synthesized Result

## 5.6 Sensitivity analysis

Sensitivity analysis was conducted for the decision of performance or prescriptive code for Hong Kong and New York City. This was done to determine if the decision outcome is sensitive to any particular parameters selected and assessed in the project. To do this, a sensitivity analysis of all the five top-level criteria (primary issues / topics) in the "performance based code vs. prescriptive code" model was created. In order to give a better comparison, the results were showed side by side between Hong Kong and New York City as following.

From Figures 30 and 31 it can be seen that performance based code is always a better alternative in regards to the education criteria. The relatively flat slopes of both performance and prescriptive code means that the priority level of education doesn't affect the decision making between performance code or prescriptive code that much.

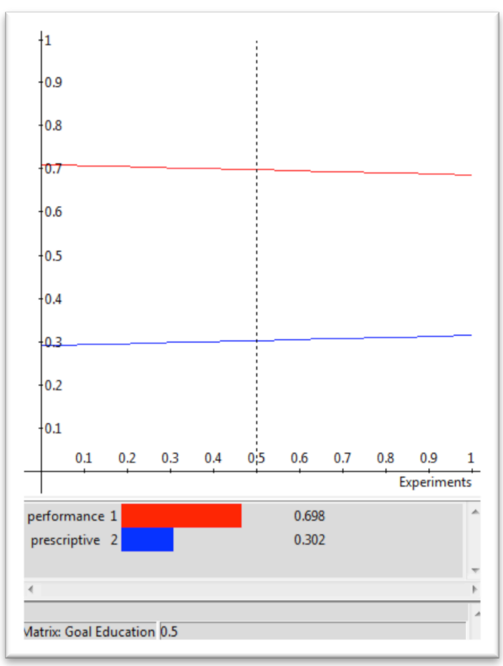



Figure 31: Education-Hong Kong

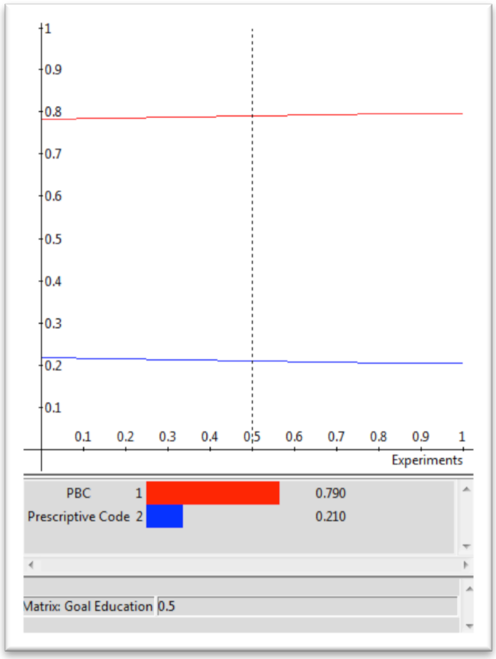



Figure 32: Education-New York City

In the Hong Kong history sensitive analysis graph (Figure 32), the two lines of performance and prescriptive code intersect with each other. The graph indicates that if the priority of History is greater than about 0.65, then prescriptive code becomes the preferred choice. If the History criteria are prioritized at a lower level, then performance will be a better choice. That is, if other users selected different rankings for history's relevancy to the issue, it is possible that the prescriptive approach should be retained according to this single criterion. The performance-based code is a better alternative in regards to the regulatory criteria as can be seen in Figure 34 and 35. As the priority level of regulatory increases, the advantage of performance based code decrease. If the decision-making is only based on the regulatory system (the priority level is equal to 100%), performance based code and prescriptive code will be equally good options.

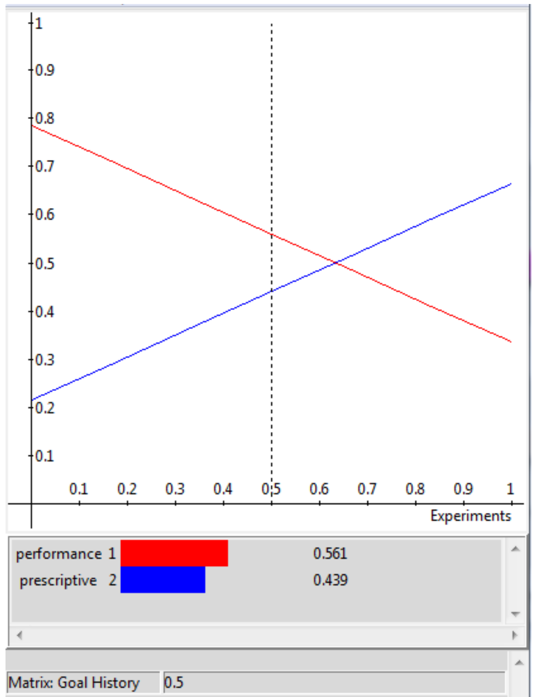



Figure 33: History-Hong Kong

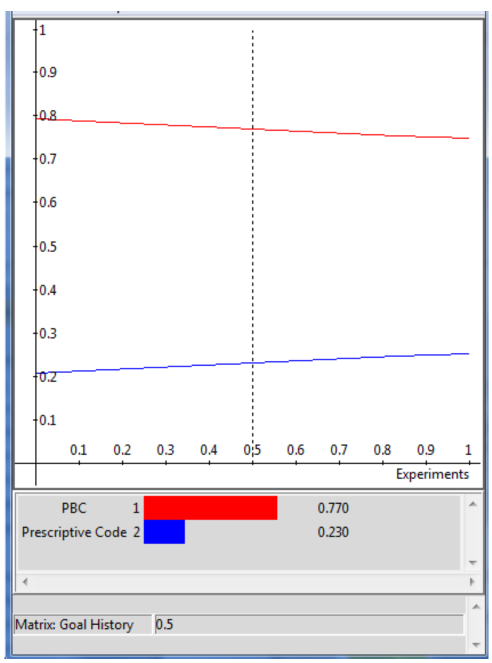



Figure 34: History-New York City

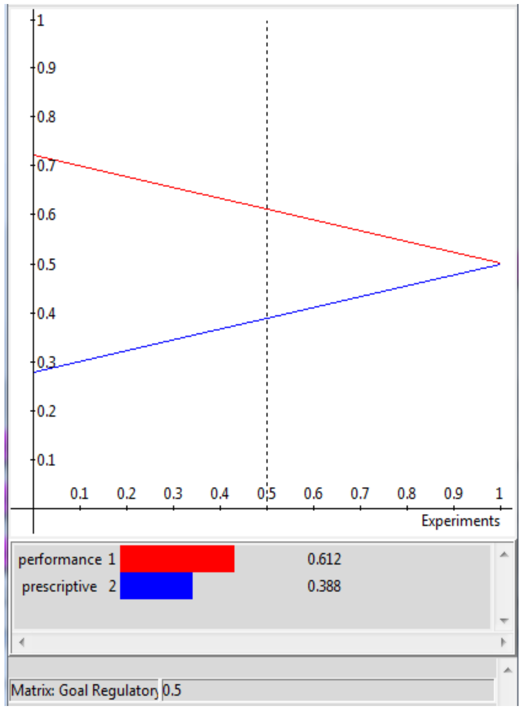



Figure 35: Regulatory-Hong Kong

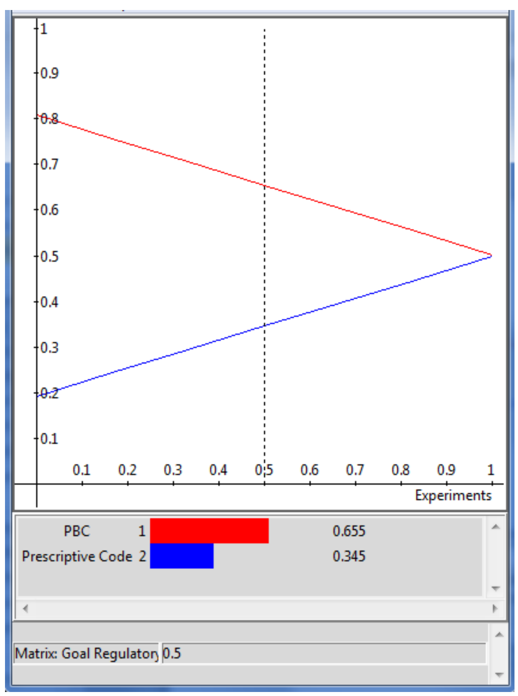



Figure 36: Regulatory-New York City

The performance-based code is always a better alternative in regards to the social criteria (Figure 36 and 37). As the priority level of social increases, the advantages of performance based code also increases. Figure 38 and 39 represents that the performance-based code is always a better alternative in regards to the technology criteria. As the priority level of technology increases, the advantage of performance based code also increases. It is noticeable that since we only have two alternatives, the lines of performance and prescriptive always mirror each other horizontally and the sum of these two at the same vertical line will always add up to 1.

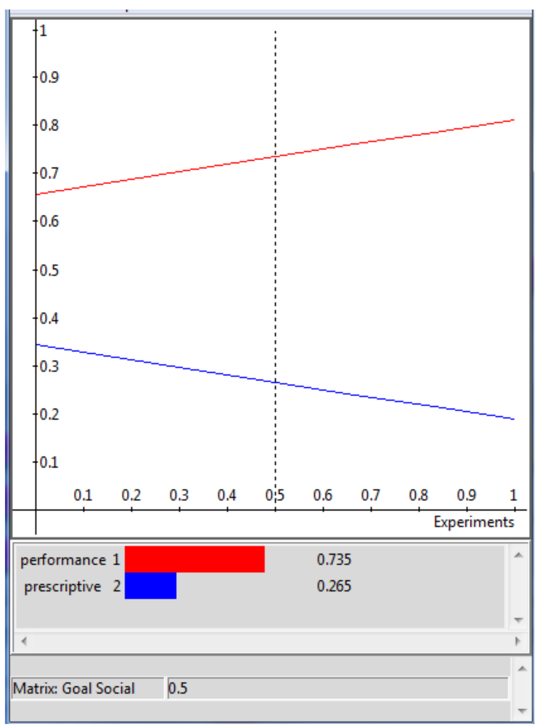



Figure 37: Social-Hong Kong

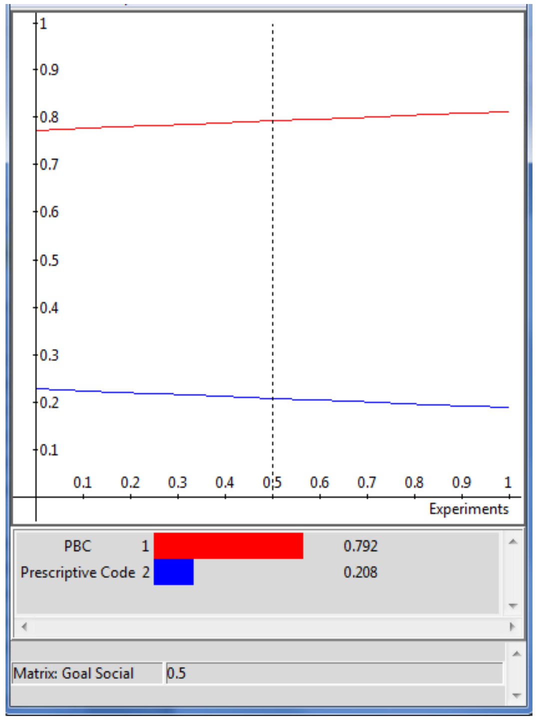



Figure 38: Social-New York City

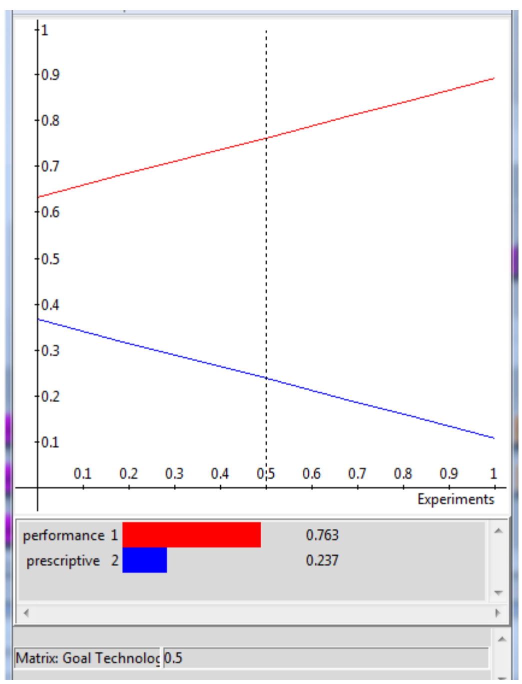



Figure 39: Technology-Hong Kong

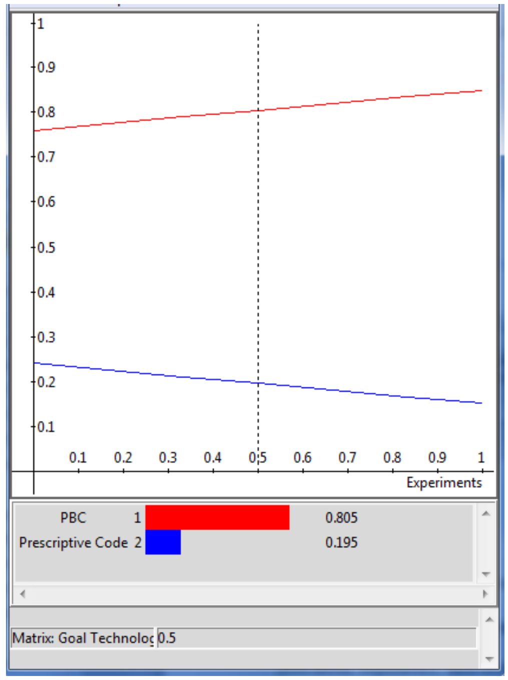



Figure 40: Technology-New York City

## Section 6: Conclusions

All the matrix analysis in the previous section are steps to achieve the final full report in the SuperDecisions model. The full report gives a comprehensive feedback about the structure of the model and all the partial results. The full report is available in the format of an HTML file in the super decision software.

The full report from both New York City and Hong Kong's models indicate that a performance based fire code will be a better alternative in regards to the advantages from social, history, education, regulatory, and technology standpoint. However, from the complete analysis, it was indicated that performance based code is only 70.56% of a perfect fire code for Hong Kong and 78.46% for New York City.

As was discussed in the background and literature review sections, there are certain limitations for both performance based code and prescriptive code. For example, the prescriptive code is very rigid, which may hinder innovation and introduce cost, but it is easy to use by enforcement officials. The performance code allows innovation and can help reduce building costs, but requires more engineering time (and cost) and can be difficult for enforcement officials to review and approve.

Therefore, based on issues associated with both prescriptive and performance codes, it is suggested that an ideal way to solve this problem is to have a combined code that has advantages of both codes. This has in fact been the approach most countries, which have implemented performance based building codes, have taken (Meacham, 2009). In this case, the decision model and experience in various countries converge on the same outcome.

## Future Research

This project revealed a lot about implementation of performance based building and fire code, and whether prescriptive or performance based code was the better option for both Hong Kong and New York City. However, there were certain tasks the authors would have undertaken if it were possible.

The authors would have liked to reach out to sources other than papers written by professionals. This could have been done by phone or personal interviews. Another method would have been sending out surveys to selected individuals. This would be a good source of information because it would be very up to date and credible.

Even so, by using outcomes from the literature search, the AHP models could be successfully structured and run to obtain outcomes. However, the authors are not professionals in the field of fire protection engineering. One possible future exploration to address this could look into how the results might change if professionals in the field of fire protection engineering (e.g., fire protection engineers, enforcement officials, building owners, fire department, etc.) were to complete the model. By doing this successful comparison would be able to be made of how the authors results compared to the engineers results. This would hopefully confirm the outcome that performance based fire code is a higher-ranking option than prescriptive fire code. It would also be interesting to see if professionals in the field of fire protection engineering (e.g., fire protection engineers, enforcement officials, building owners, fire department, etc.) agree with the selected criteria and sub-criteria, and if not, how those might change. More explicit consideration of cost impact would also be good.

With respect to the AHP models, there were two separate rankings that had to be done because of the evaluation of both New York City and Hong Kong. The authors separated these models, and each took one to rank. Because of this there could be some personal bias between the results. Such bias could make it difficult to be sure if there is difference in the rankings because of the difference in the cities, or because two separate people ranked them. If both of the authors could rank all models together and compare, the results could again be further confirmed.

## References


Al-Harbi, K. M. (2001). Application of the AHP in project management. *International journal of project management, 19*(1), 19-27.

Babrauskas, V. (2000). Performance-Based Building Codes: What Will Happen to the Levels of Safety? Downloaded from Fire Science and Technology Inc., https://doctorfire.com/FSE_codes_story.pdf, latest accessed on 04.29.13.

Bello-Dambatta, A. "Simple AHP Hierarchy." Photo. 24 April. 2013. October 2009

http://www.sciencedirect.com/science/article/pii/S1474034609000354

Begley, J. (2004). Performance-Based Fire Safety Design. Published on September 2004. Downloaded from FacilitiesNet, http://www.facilitiesnet.com/firesafety/article/PerformanceBased-Fire-Safety-Design--2017, latest accessed on 04.29.13

Bloomberg, M. R., Scoppetta, N., Cassano, S., Bazel, J., & Hansen, J. NEW YORK CITY FIRE CODE. Local Law No.26 of 2008 (Effective July 1, 2008), downloaded from Fire Department City of New York, http://firesafetydirector.com/fire_code_new/fire%20code%20eff.%2007-01-08.pdf, latest accessed on 04.29.13.

Borst, N. (2012). Urbanization and Economic Growth in China. Published on September 12th, 2012. Downloaded from Peterson Institute for International Economics, http://www.piie.com/blogs/china/?p=1508, latest accesssed on 04.29.13.

BPMSG (Producer). (2010). Analytic Hierarchy Process AHP - Business Performance Management. *Analytic Hierarchy Model Tutorials*. Retrieved from https://www.youtube.com/watch?v=18GWVtVAAzs

Building Codes in the United States, an Overview. Downloaded from the Composting Toilet Store,http://www.composting-toilet-store.com/Building_Codes_in_the_United_States_s/105.htm,latest accesssed on 04.29.13.

Bukowski, R. (1995). International Activities for Developing Performance-Based Fire Codes. *Fire Safety Design of Buildings and Fire Safety Engineering*, 25-27.

Bukowski, R. W. (1994). Developing rational, performance-based fire safety requirements in model building codes. In V. Babraukskas (Ed.), (Vol. 18, pp. 173-191). Fire Materials.

Bukowski, Richard. "The Role of Standards in a Performance-based Building Regulatory System." *fire.nist.gov*. National Institue of Standards and Technology. Web. 26 Apr 2013.

Chang, C.-W., Wu, C.-R., Lin, C.-T., & Chen, H.-C. (2007). An application of AHP and sensitivity analysis for selecting the best slicing machine. *Computers & Industrial Engineering, 52*(2), 296-307.

Chow, G. C., & Li, K. W. (2002). China's Economic Growth: 1952–2010*. *Economic Development and Cultural Change, 51*(1), 247-256.

Chow, W. K. (2002). Preliminary views on implementing engineering performance-based fire codes in Hong Kong: what should be done? *International Journal on Engineering Performance-Based Fire Codes, 4*(1), 1-9.

Chow, W. K. (2011). Open kitchen fires in tall residential buildings. *CPD lecture organized by Research Centre for Fire Engineering, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, 5*.

Chow, W. K. Concerns on Applying Performance-Based Design for DeterminingBuilding Fire Safety. Retrieved 03/16/13, from Architectural EngineeringTechnology https://docs.google.com/viewer?a=v&q=cache:XPj9nzL0vIQJ:www.omicsgroup.org/journals/2168-9717/pdfdownload.php?download%3D2168-9717-2-e109.pdf+Concerns+on+applying+performance-based+design+for+determing+building+fire+safety&hl=en&gl=us&pid=bl&srcid=ADGEEShOnV8l5u5YBiend9pXPXh9z9WuCIH2MGt9NUHjV6I8wPwQX2X64RWTNzYt8QmU2CjMpiqhtQsM_V9CEPr2vZ6AWaKjrFFzkkbUWYv_B15-olZjkUxH9RV-G6S4yf-g12o9G6L2&sig=AHIEtbQsQ9qOh0SYy-COSZZQv2u9FlwY7Q, latest accessed on 04.29.13

Department, F. S. Introduction to the Fire Safety Ambassador Club. Downloaded from Fire Safety Ambassador of Hong Kong, http://www.fsaclub.org.hk/lang/eng/sub.php?page=intro, latest accessed on 04.29.13.

Fang, G. U.S./China Differences and Their Impacts on Business Behaviors, page 5-11. http://www.wcsr.com/resources/pdfs/Fang_ArticleUSChina.pdf, latest accessed on 04.29.13.

FEMA. (1991). Highrise Office Building Fire One Meridian Plaza. *Technical Report Series, U.S. Fire Administration*, published on February 1991 in Philadelphia, PA. USFA-TR-04.

Downloaded from http://www.usfa.fema.gov/downloads/pdf/publications/tr-049.pdf, latest accessed on 04.29.13.

Fülöp, J. (2005). *Introduction to decision making methods, page 1-15*. Downloaded from Laboratory of Operations Research and Decision Systems, Computer and Automation Institute, Hungarian Academy of Sciences http://academic.evergreen.edu/projects/bdei/documents/decisionmakingmethods.pdf, latest accessed on 04.29.13.

Globalist. China VS America, Learning Strategy in the 21st Century. Published on August 25, 2008. Downloaded from online magazine Globalist http://www.theglobalist.com/storyid.aspx?storyid=5264. Latest accessed on 04.29.13.

Hadjisophocleous, G., & Benichou, N. (2000). Development of performance-based codes, performance criteria and fire safety engineering methods (pp. 127-142). International Journal on Engineering Performance-Based Fire Codes.

Hall, J. R. (2009). *High-rise building fires*: National Fire Protection Association.

Hamans, C. (18-10-2012). Fire Safety in Sustainable Assessment in Buildings. Retrieved 03/16/2013 http://www.slideshare.net/chrishamans-esc/fire-safety-in-the-sustainability-assessment-of-buildings

Hill, M. How do the building codes and standards in China compare with those in the U.S.?

Hofmeister, C. E. (April 2010). Prescriptive to Performance-Based Design in Green Buildings. Retrieved 03/16/13 http://magazine.sfpe.org/fire-protection-design/prescriptive-performance-based-design-green-buildings

Huang, Y. (2002). A room of one's own: housing consumption and residentialcrowding in transitional urban China. Envioronment and Planning A 2003, Volume 35, page 591-614, downloaded from http://www.albany.edu/~yhuang/Huang_ARoomOfOnesOwn.pdf, latest accessed on 04.29.13

Underwriters Laboratories (UL). Magazine article downloaded from http://www.inc.com/encyclopedia/underwriters-laboratories-UL.html, latest accessed on 04.29.13

Klein, MJ. "Hong Kong Population Density." Photo. 23 Apr. 2013. http://www.thenhbushman.com/2007/11/29/hong-kong-part-iii-street-market/

Kong, B. D. o. H. (2011). Code of Practice for Fire Safety in Buildings. Retrieved 03/16/2013 http://www.bd.gov.hk/english/documents/code/fs_code2011.pdf

Li, Y. (2011). THE IMPACTS OF CHINA HOUSING REFORM ON RESIDENTS' LIVING CONDITIONS. Published in 1986. Downloaded from https://scholarsbank.uoregon.edu/xmlui/handle/1794/11498, latest accessed on 04.29.13

Law, M., "Fire Safety Design Practices in the United Kingdom - New Regulations," Proceedings of the Conference on Fire Safety Design in the 21st Century, ISBN 1-881172-01-5, Worcester, MA.

Lo, Shane Siu-hang. "Running Head:Fire Safety Ambassador (FSA Scheme in Hong Kong, China." usfa.fema.gov. Hong Kong Fire Services Department, August 2008. Web. 23 Apr 2013. <http://www.usfa.fema.gov/pdf/efop/efo42378.pdf>.

Lucht, D.A., Ed., Proceedings of the Second Conference on Fire Safety Design in the 21st Century, WPI, 9-11June 1999, Worcester, MA

Liebing, R. W. (1987). *Construction regulations handbook*: Wiley.

Meacham, Brian. "The Evolution of Performance-Based Codes and Fire Safety Design Methods." fire.nist.gov. National Institue of Standards and Technology, August 1996. Web. 23 Apr 2013. <http://fire.nist.gov/bfrlpubs/fire98/PDF/f98125.pdf>.

Meacham, B. J. (1997). *Concepts of a performance-based building regulatory system for the United States*: National Institute of Standards and Technology. Building and Fire Research Laboratory.

Meacham, B. J. (2009). Performance-Based Building Regulatory Systems, Principles and Experiences. Published in July 2009. Downloaded from Inter-jurisdictional Regulatory Collaboration Committee (IRCC), http://www.irccbuildingregulations.org/pdf/IRCCGuidelines-PrinciplesandPractices09.pdf, latest accessed on 04.29.13

Neale, R. (2010). Prescriptive or Peformance: You Make the Call part 2 (Vol. 5, pp. 1-8). Loss Prevention & Risk Management Newsletter: Hospitality Lawyer.

“New York City Skyline.” Photo. Luxurylink.com 23 Latest accessed on Apr. 2013. <http://www.luxurylink.com/fivestar/new-york-city/photos/968-new-york-city-skyline>

Niu, J. (2004). Some significant environmental issues in high-rise residential building design in urban areas. *Energy and buildings, 36*(12), 1259-1263.

Pilzer, D. (2005). Performance Based Building Regulations. In M. Jasuja (Ed.). Israel: Performance Based Building Thematic Network.

Reported from Shanghai 11.15 fire to see how the media respond to emergencies. http://eng.hi138.com/?i401763_Reported-from-Shanghai-11.15-fire-to-see-how-the-media-respond-to-emergencies

"Report of the New York City New York State Task Force on Building and Fire Safety." nysenate.gov. N.p., 2010. Web. 23 Apr 2013. <http://www.nysenate.gov/files/pdfs/NYC NYS

Routley, J. G., Jennings, C., & Chubb, M. (1991a). *High-rise Office Building Fire, One Meridian Plaza Philadelphia, Pennsylvania (February 23, 1991)*: Federal Emergency Management Agency, US Fire Administration, National Fire Data Center.

Routley, J. G., Jennings, C., & Chubb, M. (1991b). High-Rise Office Building Fire, One Meridian Plaza, Philadelphia, Pennsylvania. *FEMA (Federal Emergency Management Agency)*.

Rui, R. (2010). Identities of Shanghai Fire Victims Kept Secret *Civil rights activist calls on public to investigate*. Pubulished on November 30, 2010, downloaded from http://www.theepochtimes.com/n2/china-news/identities-of-shanghai-fire-victims-kept-secret-46779.html, latest accessed on 04.29.13

Saaty, T. L. (1988). *What is the analytic hierarchy process?* : Springer.

Sheehan, K. (1994). Jury to Determine Blame for One Meridian Plaza. Published on March 14th, 1994. Downloaded from Philly.com, http://articles.philly.com/1994-03-14/news/25852243_1_minor-blaze-fire-equipment-water-pressure, latest accessed on 04.29.13.

*Shelhamer, C.* How Fire Disaster Shaped the Evolution of the New York City Building Code. Retrieved 03/16/13 http://bsj.iccsafe.org/2010Dec/features/nyc_code_history.html), latest accessed on 04.29.13.

Tavares, R. M. (2008). PRESCRIPTIVE CODES VS. PERFORMANCE-BASED CODES: WHICH ONE IS THE BEST FIRE SAFETY CODE FOR THE BRAZILIAN CONTEXT? *Safety Science Monitor, 12*(1), 1-10.

Three more suspects detained over Shanghai high-rise fire. (2010, 2010/12/24/). Brief article, *BBC Monitoring International Reports*. Retrieved from http://go.galegroup.com/ps/i.do?id=GALE, latest accessed on 04.29.13.

Tsui, S. C. PERFORMANCE-BASED FIRE SAFETY DESIGN IN HONG KONG. International Journal on Engineering Performance-Based Fire Codes, Volume 6, Number 4, p.223-229, 2004, downloaded from http://www.bse.polyu.edu.hk/researchCentre/Fire_Engineering/summary_of_output/journal/IJEPBFC/V6/p.223-229.pdf, latest accessed on 04.29.13

Tsui, S. C., & Chow, W. K. (2002). Review on the Local Code of Practice for the Provision of Means of Escape. *International Journal on Engineering Performance-Based Fire Codes, 4*(2), 35-50.

.U.S. Fire Administration. HIGHRISE FIRES. *Volume 2, Issue 18, January 2002.* Downloaded from Topical Fire Research Series. (2002). http://www.usfa.fema.gov/downloads/pdf/tfrs/v2i18-508.pdf, latest accessed on 04.29.13

Wang, H., & Fan, W. (1997). Progress and problems of fire protection in China. *Fire safety journal, 28*(3), 191-205.

Waters, J. R. (2000). *PERFORMANCE CODES and their possible effect on fire department operations*: National Fire Academy.

Wilson, W. (1908). *Constitutional government in the United States*: Transaction Pub.

Worcester Fire Prevention Division. Worcester City Government/Department&Division/Fire Downloaded from http://www.worcesterma.gov/fire/prevention. Latest accessed on 04.29.13

Xinhua. (2010). 42 Killed in High Rise Building Fire in Shanghai, *China Daily*. Retrieved from http://www.chinadaily.com.cn/china/2010-11/15/content_11552718.htm, latest accessed on 04.29.13.

## Bibliography


Babrauskas, V. (2000). Performance-Based Building Codes: What Will Happen to the Levels of Safety? Downloaded from Fire Science and Technology Inc., https://doctorfire.com/FSE_codes_story.pdf, latest accessed on 04.29.13.

Begley, J. (2004). Performance-Based Fire Safety Design. Published on September 2004. Downloaded from FacilitiesNet, http://www.facilitiesnet.com/firesafety/article/PerformanceBased-Fire-Safety-Design--2017, latest accessed on 04.29.13

Bello-Dambatta, A. "Simple AHP Hierarchy." Photo. 24 April. 2013. October 2009

http://www.sciencedirect.com/science/article/pii/S1474034609000354

Bloomberg, M. R., Scoppetta, N., Cassano, S., Bazel, J., & Hansen, J. NEW YORK CITY FIRE CODE. Local Law No.26 of 2008 (Effective July 1, 2008), downloaded from Fire Department City of New York, http://firesafetydirector.com/fire_code_new/fire%20code%20eff.%2007-01-08.pdf, latest accessed on 04.29.13.

BPMSG (Producer). (2010). Analytic Hierarchy Process AHP - Business Performance Management. Analytic Hierarchy Model Tutorials. Retrieved from https://www.youtube.com/watch?v=18GWVtVAAzs

Bukowski, R. (1995). International Activities for Developing Performance-Based Fire Codes. Fire Safety Design of Buildings and Fire Safety Engineering, 25-27.

Bukowski, R. W. (1994). Developing rational, performance-based fire safety requirements in model building codes. In V. Babraukskas (Ed.), (Vol. 18, pp. 173-191). Fire Materials.

Bukowski, Richard. "The Role of Standards in a Performance-based Building Regulatory System." fire.nist.gov. National Institue of Standards and Technology. Web. 26 Apr 2013.

Canniff, Andrew, Jin Kyung Kim, and Cing Lun Thang. "Factors Affecting the Transition from Prescriptive to Performance- Fire Codes in Korea, Poland and Brazil." 3 Mar. 2012.

Chow, W. K. (2002). Preliminary views on implementing engineering performance-based fire codes in Hong Kong: what should be done? International Journal on Engineering Performance-Based Fire Codes, 4(1), 1-9.

Chow W.K. (2012) Concerns on Applying Performance-Based Design for Determining Building Fire Safety. J Archit Eng Tech 1:e109. doi:10.4172/2168- 9717.1000e109

Fülöp, J. (2005). Introduction to decision making methods, page 1-15. Downloaded from Laboratory of Operations Research and Decision Systems, Computer and Automation Institute, Hungarian Academy of Sciences http://academic.evergreen.edu/projects/bdei/documents/decisionmakingmethods.pdf, latest accessed on 04.29.13.

"Guidelines for the Introduction of Performance-Based Building Regulations (Discussion Paper)." Irccbuildingregulations.org. The Inter-Jurisdictional Regulatory Collaboration Committee, 01 May 1998. Web. 23 Apr 2013. <http://www.irccbuildingregulations.org/pbbr_doc.html>.

Hamans, C. (18-10-2012). Fire Safety in Sustainable Assessment in Buildings. Retrieved 03/16/2013 http://www.slideshare.net/chrishamans-esc/fire-safety-in-the-sustainability-assessment-of-buildings

Hill, M. How do the building codes and standards in China compare with those in the U.S.?

Hofmeister, C. E. (April 2010). Prescriptive to Performance-Based Design in Green Buildings. Retrieved 03/16/13 http://magazine.sfpe.org/fire-protection-design/prescriptive-performance-based-design-green-buildings

Underwriters Laboratories (UL). Magazine article downloaded from http://www.inc.com/encyclopedia/underwriters-laboratories-UL.html, latest accessed on 04.29.13

Klein, MJ. "Hong Kong Population Density." Photo. 23 Apr. 2013. <http://www.thenhbushman.com/2007/11/29/hong-kong-part-iii-street-market/>

Kong, B. D. o. H. (2011). Code of Practice for Fire Safety in Buildings. Retrieved 03/16/2013 http://www.bd.gov.hk/english/documents/code/fs_code2011.pdf

Law, M., "Fire Safety Design Practices in the United Kingdom - New Regulations," Proceedings of the Conference on Fire Safety Design in the 21st Century, ISBN 1-881172-01-5, Worcester, MA.

Lo, Shane Siu-hang. "Running Head:Fire Safety Ambassador (FSA Scheme in Hong Kong, China." usfa.fema.gov. Hong Kong Fire Services Department, August 2008. Web. 23 Apr 2013. <http://www.usfa.fema.gov/pdf/efop/efo42378.pdf>.

Lucht, D.A., Ed., Proceedings of the Second Conference on Fire Safety Design in the 21st Century, WPI, 9-11June 1999, Worcester, MA

Meacham, Brian. "The Evolution of Performance-Based Codes and Fire Safety Design Methods." fire.nist.gov. National Institue of Standards and Technology, August 1996. Web. 23 Apr 2013. <http://fire.nist.gov/bfrlpubs/fire98/PDF/f98125.pdf>.

Meacham, B. J. (1997). Concepts of a performance-based building regulatory system for the United States: National Institute of Standards and Technology. Building and Fire Research Laboratory.

Meacham, B. J. (2009). Performance-Based Building Regulatory Systems, Principles and Experiences. Published in July 2009. Downloaded from Inter-jurisdictional Regulatory Collaboration Committee (IRCC), http://www.irccbuildingregulations.org/pdf/IRCCGuidelines-PrinciplesandPractices09.pdf, latest accessed on 04.29.13

Neale, R. (2010). "Prescriptive or Performance: You Make the Call (Vol. V, pp. 5). Loss Prevention and Risk Management June Newsletter: HospitalityLawyer.com.

“New York City Skyline.” Photo. Luxurylink.com 23 Apr. 2013. <http://www.luxurylink.com/fivestar/new-york-city/photos/968-new-york-city-skyline>

"Report of the New York City New York State Task Force on Building and Fire Safety." nysenate.gov. N.p., 2010. Web. 23 Apr 2013. <http://www.nysenate.gov/files/pdfs/NYC NYS

Saaty, T. L. (1988). What is the Analytic Hierarchy Process? : Springer.

Shelhamer, C. How Fire Disaster Shaped the Evolution of the New York City Building Code. Retrieved 03/16/13 http://bsj.iccsafe.org/2010Dec/features/nyc_code_history.html)

Tavares, R. M. (2008). PRESCRIPTIVE CODES VS. PERFORMANCE-BASED CODES: WHICH ONE IS THE BEST FIRE SAFETY CODE FOR THE BRAZILIAN CONTEXT? Safety Science Monitor, 12(1), 1-10.

Tsui, S. C. PERFORMANCE-BASED FIRE SAFETY DESIGN IN HONG KONG. International Journal on Engineering Performance-Based Fire Codes, Volume 6, Number 4, p.223-229, 2004, downloaded from http://www.bse.polyu.edu.hk/researchCentre/Fire_Engineering/summary_of_output/journal/IJEPBFC/V6/p.223-229.pdf, latest accessed on 04.29.13

Tsui, S. C., & Chow, W. K. (2002). Review on the Local Code of Practice for the Provision of Means of Escape. International Journal on Engineering Performance-Based Fire Codes, 4(2), 35-50.

Waters, J. R. (2000). PERFORMANCE CODES and their possible effect on fire department operations: National Fire Academy. Administration, U. S. F. (2002). Topical Fire Research Series Highise Fires (Vol. 2). fema.gov: fema.

# Appendices

## Appendix 1: Alternative Ranking

### Appendix 1.1: Alternative Ranking: Hong Kong

| Graphic | Alternatives | Total | Normal | Ideal | Ranking |
|---|---|---|---|---|---|
| | Amount of Research and Papers available | 0.0460 | 0.0919 | 0.3784 | 4 |
| | Building departments outlook | 0.0056 | 0.0111 | 0.0457 | 13 |
| | Contractors compatibility with prescriptive code | 0.0099 | 0.0197 | 0.0811 | 10 |
| | Effect from the Establishment of Hong Kong SAR | 0.0446 | 0.0891 | 0.3669 | 5 |
| | Existance of Effective Nonprofit Organizations | 0.0886 | 0.1772 | 0.7294 | 2 |
| | How Performance Based Codes Effect Fire Departments | 0.0278 | 0.0556 | 0.2287 | 8 |
| | Insurance Companies benefits with prescriptive code | 0.0072 | 0.0144 | 0.0591 | 11 |
| | Lack of Education of Code Officials | 0.0042 | 0.0084 | 0.0347 | 14 |
| | Level of innovation in current building | 0.1215 | 0.2430 | 1.0000 | 1 |
| | Quantity of Fire Labs Available for Testing and Research | 0.0174 | 0.0347 | 0.1429 | 9 |
| | Quantity of Universities with Fire Protection Engineering | 0.0278 | 0.0557 | 0.2292 | 7 |
| | Regional/General System Outlook | 0.0056 | 0.0111 | 0.0457 | 12 |
| | Relationship with Performance Based Fire Code Countries | 0.0494 | 0.0988 | 0.4067 | 3 |
| | Results from Incidents | 0.0446 | 0.0891 | 0.3669 | 6 |

**Accelerators**

| Graphic | Alternatives | Total | Normal | Ideal | Ranking |
|---|---|---|---|---|---|
| | Amount of Research and Papers available | 0.0116 | 0.0232 | 0.1225 | 10 |
| | Building departments outlook | 0.0945 | 0.1889 | 1.0000 | 2 |
| | Contractors compatibility with prescriptive code | 0.0189 | 0.0379 | 0.2006 | 8 |
| | Effect from the Establishment of Hong Kong SAR | 0.0435 | 0.0871 | 0.4608 | 5 |
| | Existance of Effective Nonprofit Organizations | 0.0021 | 0.0043 | 0.0226 | 14 |
| | How Performance Based Codes Effect Fire Departments | 0.0189 | 0.0378 | 0.2000 | 9 |
| | Insurance Companies benefits with prescriptive code | 0.0256 | 0.0511 | 0.2706 | 7 |
| | Lack of Education of Code Officials | 0.0795 | 0.1590 | 0.8416 | 3 |
| | Level of innovation in current building | 0.0070 | 0.0140 | 0.0740 | 12 |
| | Quantity of Fire Labs Available for Testing and Research | 0.0489 | 0.0978 | 0.5177 | 4 |
| | Quantity of Universities with Fire Protection Engineering | 0.0076 | 0.0152 | 0.0803 | 11 |
| | Regional/General System Outlook | 0.0945 | 0.1889 | 1.0000 | 1 |
| | Relationship with Performance Based Fire Code Countries | 0.0039 | 0.0077 | 0.0410 | 13 |
| | Results from Incidents | 0.0435 | 0.0871 | 0.4608 | 6 |

**Decelarators**

## Appendix 1.2: Alternative Ranking: New York City

| Graphic | Alternatives | Total | Normal | Ideal | Ranking |
|---|---|---|---|---|---|
| | Amount of Research and Papers available | 0.0286 | 0.0572 | 0.2355 | 6 |
| | Code Officials Outlook | 0.0069 | 0.0139 | 0.0572 | 12 |
| | Contractors compatibility with prescriptive code | 0.0105 | 0.0210 | 0.0866 | 10 |
| | Effects of 9/11 | 0.0743 | 0.1486 | 0.6114 | 3 |
| | Existance of Effective Nonprofit Organizations | 0.0817 | 0.1634 | 0.6725 | 2 |
| | How Performance Based Codes Effect Fire Departments | 0.0276 | 0.0551 | 0.2269 | 7 |
| | Insurance Companies benefits with prescriptive code | 0.0072 | 0.0145 | 0.0595 | 11 |
| | Lack of Education of Code Officials | 0.0040 | 0.0080 | 0.0330 | 14 |
| | Level of innovation in current building | 0.1215 | 0.2430 | 1.0000 | 1 |
| | Quantity of Fire Labs Available for Testing and Research | 0.0174 | 0.0347 | 0.1429 | 8 |
| | Quantity of Universities with Fire Protection Engineering | 0.0454 | 0.0908 | 0.3738 | 5 |
| | Regional/General System Outlook | 0.0044 | 0.0088 | 0.0360 | 13 |
| | Relationship with Performance Based Fire Code Countries | 0.0556 | 0.1112 | 0.4577 | 4 |
| | Results from Incidents | 0.0149 | 0.0297 | 0.1223 | 9 |

**Accelerators**

| Graphic | Alternatives | Total | Normal | Ideal | Ranking |
|---|---|---|---|---|---|
| | Amount of Research and Papers available | 0.0123 | 0.0246 | 0.1096 | 10 |
| | Code Officials Outlook | 0.0501 | 0.1003 | 0.4463 | 3 |
| | Contractors compatibility with prescriptive code | 0.0456 | 0.0912 | 0.4060 | 4 |
| | Effects of 9/11 | 0.0141 | 0.0282 | 0.1257 | 9 |
| | Existance of Effective Nonprofit Organizations | 0.0051 | 0.0102 | 0.0452 | 14 |
| | How Performance Based Codes Effect Fire Departments | 0.0168 | 0.0336 | 0.1494 | 8 |
| | Insurance Companies benefits with prescriptive code | 0.0300 | 0.0599 | 0.2666 | 7 |
| | Lack of Education of Code Officials | 0.1108 | 0.2216 | 0.9861 | 2 |
| | Level of innovation in current building | 0.0053 | 0.0107 | 0.0475 | 13 |
| | Quantity of Fire Labs Available for Testing and Research | 0.0373 | 0.0747 | 0.3322 | 6 |
| | Quantity of Universities with Fire Protection Engineering | 0.0123 | 0.0246 | 0.1096 | 11 |
| | Regional/General System Outlook: | 0.1124 | 0.2247 | 1.0000 | 1 |
| | Relationship with Performance Based Fire Code Countries | 0.0055 | 0.0109 | 0.0486 | 12 |
| | Results from Incidents | 0.0424 | 0.0847 | 0.3770 | 5 |

Decelerators

# Appendix 2: Decision model Full report

## Appendix 2.1: Hong Kong

| | |
|---|---|
| **Alternative(s) in it:** | • performance<br>• prescriptive |
| **Network Type:** | Bottom level |
| **Formula:** | `Not applicable` |
| **Clusters/Nodes** | • **1Goals:** *This is the Goals Cluster the top level in the hierarchy*<br>◦ **Goal:** *Which factor is the most influential decelerator to the implementation of a performance based fire code in Hong Kong.*<br>• **alternatives:** *description*<br>◦ **performance:** *description*<br>◦ **prescriptive:** *description*<br>• **Criteria:** *description*<br>◦ **Education:** *Factors in Education which are of importance to the goal*<br>◦ **History:** *Factors in History which are of importance to the goal*<br>◦ **Regulatory:** *Regulatory factors which are of importance to the goal*<br>◦ **Social:** *Social factors which are of importance to the goal*<br>◦ **Technology:** *Factors in Technology which are of importance to the goal*<br>• **reasons:** *description*<br>◦ **Amount of Research and Papers available:** *EDUCATION-Research and papers that have been created are what will be analyzed when looking into performance based fire code. It is necessary to make sure there has been enough research done, and papers written if a performance based fire code is to be implemented.*<br>◦ **Building departments outlook:** *REGULATORY-In Hong Kong, the building department consists of new building division, existing building division, and mandatory building inspection division. There was an indication that the Hong Kong building officials had considered that performance-based engineering might be used for modern complex buildings. However, they were still not fully comfortable in accepting the fire safety engineering design because of their limited knowledge, inadequate fire and evacuation prediction tools, and the unclear liability.*<br>◦ **Contractors compatibility with prescriptive code:** *SOCIAL- Currently, contractors are set up to deal with prescriptive code much better than performance based code. Because of this if the contractors are taken into consideration prescriptive code may seem like the better option*<br>◦ **Effect from the Establishment of Hong Kong SAR:** *HISTORY- The establishment of Hong Kong SAR impacted the political and social structure in Hong Kong to a certain extent. It may also meant that Hong Kong's fire safety regulations were changed from the previous British code in 1997.Once this change was made Hong Kong was very eager for change, and is currently very open minded.*<br>◦ **Existance of Effective Nonprofit Organizations:** *SOCIAL- In countries reviewed, like Australia, New Zealand and the USA, non-profit organizations help develop and facilitate implementation of performance based codes. If these non-profit organizations exist, then it would be easier to bring in performance based fire code.* |

- **How Performance Based Codes Effect Fire Departments:** *REGULATORY- Performance based codes can create added protection of life to occupants and fire fighters.*
- **Insurance Companies benefits with prescriptive code:** *SOCIAL- Performance based codes do not necessarily address protection of property (varies by country), and this may not be appealing for insurance companies. Prescriptive code does deal with property protection.*
- **Lack of Education of Code Officials:** *EDUCATION- Currently code officials work with a prescriptive fire code, and do not necessarily understand all of the engineering principles and mathematics of analysis and modeling used in support of a performance based design. If a performance based code was implemented code officials would have to be educated on fire protection engineering.*
- **Level of innovation in current building:** *TECHNOLOGY- Current buildings are generally more technologically advanced than previous. New technologically advanced construction is very difficult to design using prescriptive code. Hence, the use of performance based fire code would make things easier for innovative materials and systems.*
- **Quantity of Fire Labs Available for Testing and Research:** *TECHNOLOGY- Fire laboratory functions range from research of materials to testing of materials for code compliance for companies. With the implementation of performance-based code, laboratories will be used quite often. If there are not enough laboratories it could be difficult to implement a performance-based code.*
- **Quantity of Universities with Fire Protection Engineering:** *EDUCATION-Universities with fire protection engineering are where many research and papers come from. Many countries have worked very closely with universities when implementing a performance-based code. Hence, there has to be enough universities working in related areas in order to successfully implement a performance based fire code.*
- **Regional/General System Outlook:** *REGULATORY- The regulatory system in the region (jurisdiction) where a performance code is desired will have to go through many steps in order to implement a performance based code. If a current prescriptive code results in a relatively safe environment, and industry is okay with the current situation, there may be little motivation for the introduction of performance-based code.*
- **Relationship with Performance Based Fire Code Countries:** *SOCIAL- If the city is able to have good relationships with other countries who have already implemented performance based code, and then they may be able to get help and insight into the implementation. Also, the city can look into what others have done and benefit from lessons learned.*
- **Results from Incidents:** *HISTORY- Many code changes have happened from fires. There is a question of whether this constant investigation and modification to prescriptive codes will carry forward into the implementation and maintenance of performance based codes.*

| Graphic | Alternatives | Total | Normal | Ideal | Ranking |
|---|---|---|---|---|---|
| | performance | 0.2490 | 0.7469 | 1.0000 | 1 |
| | prescriptive | 0.0844 | 0.2531 | 0.3388 | 2 |

## Appendix 2.2: New York City

| | |
|---|---|
| **Alternative(s) in it:** | • PBC<br>• Prescriptive Code |
| **Network Type:** | Bottom level |
| **Formula:** | `Not applicable` |

**Clusters/Nodes**

- **1Goals:** *This is the Goals Cluster, the top level in the hierarchy.*
    - **Goal:** *By looking into what factor is the most important accelerator towards performance based fire code we will be able to understand if performance based or prescriptive is the better option. From our analysis of accelerators and decellerators we concluded that a high accelerator is a low decelerator. We will use these findings in this model.*
- **Alternatives:** *description*
    - **PBC:** *From a comparison of the accelerators is performance based code the best option*
    - **Prescriptive Code:** *From a comparison of decelerator and accelerators of the implementation is not implementing performance based code, hence staying with precriptive code the better option.*
- **Criteria:** *description*
    - **Education:** *Factors in Education which are of importance to the goal*
    - **History:** *Factors in History which are of importance to the goal*
    - **Regulatory:** *Regulatory Factors which are of importance to the goal*
    - **Social:** *Social Factors which are of importance to the goal*
    - **Technology:** *Factors in Technology which are of importance to the goal*
- **Criteria2:** *description*
    - **Amount of Research and Papers available:** *EDUCATION-Research and papers that have been created are what will be analyzed when looking into performance based fire code. It is necessary to make sure there has been enough research done, and papers written if a performance based fire code is to be implemented*
    - **Code Officials Outlook:** *REGULATORY- Code officials are very accustomed to using prescriptive fire code. Because of this it may be difficult to change to a performance based fire code for several reasons.*
    - **Contractors compatibility with prescriptive code:** *SOCIAL- Currently, contractors are set up to deal with prescriptive code much better than performance based code. Because of this if the contractors are taken into consideration prescriptive code may seem like the better option*
    - **Effects of 9/11:** *HISTORY- As terrible as the events of September 11, 2001 were, investigations into the fires and collapses by NIST have brought forth some positive research and recommendations for performance-based codes and performance based design*
    - **Existance of Effective Nonprofit Organizations:** *SOCIAL- In countries reviewed, like Australia, New Zealand and the USA, non-profit organizations help develop and facilitate implementation of performance based codes. If these non-profit organizations exist, then it would be easier to bring in performance based fire code.*

- **How Performance Based Codes Effect Fire Departments:** *REGULATORY- Performance based codes can create added protection of life to occupants and fire fighters.*
- **Insurance Companies benefits with prescriptive code:** *SOCIAL- Performance based codes do not necessarily address protection of property (varies by country), and this may not be appealing for insurance companies. Prescriptive code does deal with property protection (at least in USA, to some extent).*
- **Lack of Education of Code Officials:** *EDUCATION- Currently code officials work with a prescriptive fire code, and do not necessarily understand all of the engineering principles and mathematics of analysis and modeling used in support of a performance based design. If a performance based code was implemented code officials would have to be educated on fire protection engineering*
- **Level of innovation in current building:** *TECHNOLOGY- Current buildings are generally more technologically advanced than previous. New technologically advanced construction is very difficult to design using prescriptive code. Hence, the use of performance based fire code would make things easier for innovative materials and systems.*
- **Quantity of Fire Labs Available for Testing and Research:** *TECHNOLOGY- Fire laboratory functions range from research of materials to testing of materials for code compliance for companies. With the implementation of performance based code, laboratories will be used quite often. If there are not enough laboratories it could be difficult to implement a performance-based code.*
- **Quantity of Universities with Fire Protection Engineering:** *EDUCATION-Universities with fire protection engineering are where many research and papers come from. Many countries have worked very closely with universities when implementing a performance-based code. Hence, there has to be enough universities working in related areas in order to successfully implement a performance based fire code.*
- **Regional/General System Outlook:** *REGULATORY- The regulatory system in the region (jurisdiction) where a performance code is desired will have to go through many steps in order to implement a performance based code. If a current prescriptive code results in a relatively safe environment, and industry is okay with the current situation, there may be little motivation for the introduction of performance-based code.*
- **Relationship with Performance Based Fire Code Countries:** *SOCIAL- If the city is able to have good relationships with other countries who have already implemented performance based code, then they may be able to get help and insight into the implementation. Also, the city can look into what others have done and benefit from lessons learned.*
- **Results from Incidents:** *HISTORY- Many code changes have happened from fires. There is a question of whether this constant investigation and modification to prescriptive codes will carry forward into the implementation and maintenance of performance based codes.*

| Graphic | Alternatives | Total | Normal | Ideal | Ranking |
|---|---|---|---|---|---|
| | PBC | 0.2615 | 0.7846 | 1.0000 | 1 |
| | Prescriptive Code | 0.0718 | 0.2154 | 0.2745 | 2 |

# Appendix 3: Code Summary and Narrative

## Appendix 3.1: Code Summary

**WPI Solar Decathlon Competition House**

**Code Summary Report**

**Introduction**

Students and faculty at Worcester Polytechnic Institute (WPI) have teamed up with students and faculty at Ghent University in Belgium and New York University in New York to form the BMN (Belgium, Massachusetts, New York) Team for the Solar Decathlon China (SDC) 2013 competition (http://www.sdchina.org/). The design and construction of the house is required to follow both the SDC competition rules as well as the International Residential Code (IRC). The house is planned to be a one story single-family dwelling. The house is square, with a 36.9-foot (11.25 meters) long side length square shape, and a 258.334 square foot (24 square meter) closed atrium in the center. The total finished compliance area is 92 square meters, which includes two bedrooms, one “L-shape” living room, a kitchen and a technical room (see attached drawings). The design is unique for several reasons, particularly in the use of fiber reinforced polymer (FRP) panels with expanded polyurethane foam insulation. These panels, with the trade name Transonite, will be used to provide the structural system, roof and ceiling assemblies, and interior/exterior wall systems. Preliminary floor plans for the house are provided on subsequent pages.

**Applicable Code**

This code analysis is based upon the Massachusetts Residential Code (MRC), which is the 2009 edition of the International Residential Code (IRC) with Massachusetts Amendments. The following sections are particularly affecting this analysis. Analysis of structural and energy code requirements can be found under separate cover.

R302 FIRE-RESISTANT CONSTRUCTION

NFPA 13D STANDARD FOR THE INSTALLATION OF SPRINKLER SYSTEMS IN ONE- AND TWO-FAMILY DWELLINGS AND MANUFACTURED HOMES

In general, only the code acronym and number will be used to reference the above codes (e.g., MRC R302).

**General Assumptions**

Throughout this code it is assumed that the BMN house will be fully sprinkled in accordance with NFPA 13D. This is to comply with IRC requirements, which is required by the competition, even though not required by MRC.

The BMN house will use solar power as the primary energy resource.

The foyer roof will be closed for four seasons.

**Occupancy Classification**

Single-family dwelling

**Walls and Penetrations Requirements**

Exterior walls shall comply with table R302.1, which states that that if the minimum fire separation distance is > or = to 5 feet then it does not have to be fire resistance rated. Hence, the Solar House does not need to have fire rated exterior walls

Penetrations of wall or floor/ceiling assemblies are required to be fire resistance rated in accordance with section R303.3.

R302.3 does not apply to the solar house since it is not a two-family dwelling.

Through Penetrations have to be installed with approves tested fire-rated assembly, and penetrations shall be protected by and approves penetration firestop system according to R302.4.1.

R 302.4 does not apply to the solar house since it is not a townhouse.

Wall and ceiling finishes shall have a flame spread index of no more than 200, and a smoke index of no more than 450 according to R302.9. When tested in accordance with ASTM E 84 (*Standard Test Method for Surface Burning Characteristics of Building Materials*) or UL 723 (*Test for Surface Burning Characteristics of Building Materials)*.

According to R302.9.4 an alternate test method can be done in which the material has to be tested in accordance with NFPA 286 (*Standard Methods of Fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth*)

We propose to test according to NFPA 286.

Insulations must have a flame spread index of no more than 25 and a smoke developed index that does not exceed 450 when tested in accordance to ASTM E84 or UL 723 per R302.10.1.

Fire blocking requirements do not apply to the house since it is not wood framed.

Combustible Insulation has to be 3 inches from heat producing devices according to R302.13.

**Foam Plastics**

Foam Plastics must have a flame spread index of no more than 75 and shall have a smoke developed index of no more than 450 when tested at the max thickness in accordance with ASTM E84 or UL 723

Foam plastic shall be separated from the interior of the building by an *approved* thermal barrier of minimum ½ inch. The finish material has to limit the average temperature rise of the unexposed surface to no more than 250 Degrees Fahrenheit after 15 minutes of exposure when tested in accordance with ASTM E 119 (*the hourly fire resistance rating for a wall assembly test*) or UL 263 (*Fire Tests of Building Construction and Materials*). The thermal barrier shall be installed in such a manner that it will remain in place for 15 minutes based on NFPA 286.

We proposed to demonstrate thermal barrier compliance by applying the NFPA 286.

**Automatic Fire Sprinkler System**

Single-family dwellings with an aggregate area smaller than 14,400 square feet are not required to have fire sprinklers installed as per the MRC.

Where installed, automatic sprinklers shall be in accordance with NFPA 13D.

**Emergency Escape and Rescue Openings**

Per R310.1 all sleeping rooms must have one operable emergency escape or rescue opening that has a sill height of no more than 44 inches above the floor.

They must open into a direct route to a public way

According to R10.1.1 through R310.1.4:

Minimum opening area = 5.7 square feet

Minimum opening dimension = 20 inches by 24 inches in either direction.

Minimum opening width = 20 inches

**Means of Egress**

At least two egress doors shall be provided for each dwelling unit per Massachusetts Residential Code.

All dwellings shall comply with section R311.1 Massachusetts Residential Code and have an unobstructed path of horizontal and vertical travel to the egress doors.

Egress door shall be at least 32 inches wide, open 90 degrees, and a height of no less than 78 inches.

According to R311.3, each exterior door must have a landing on either side that is 36 inches in the direction of travel and a max slope of 2%.

Landings must be no more than 1½ inches lower than the top of the threshold

The hallway must be a minimum of 3ft per R311.6

**Smoke Alarms**

Smoke alarms need to be photoelectric type smoke alarms listed in accordance with UL 217 or UL 268, and must be placed in the following location per R314.3:

In each Bedroom

Outside each separate sleeping area in the vicinity of the bedrooms

If there is more than on smoke alarm in the residence the alarms need to be interconnected.

The smoke alarms must receive power from the building wiring when the residence is served from a commercial source, and must receive power from a battery when the power is interrupted.

**Clearances from Combustible Construction**

Mechanical appliances must be constructed with clearance from unprotected combustible construction in accordance with table M1306.2

## TABLE M1306.2 REDUCTION OF CLEARANCES WITH SPECIFIED FORMS OF PROTECTION[a, c, d, e, f, g, h, I, j, k, l]

| TYPE OF PROTECTION APPLIED TO AND COVERING ALL SURFACES OF COMBUSTIBLE MATERIAL WITHIN THE DISTANCE SPECIFIED AS THE REQUIRED CLEARANCE WITH NO PROTECTION (See Figures M1306.1 and M1306.2) | WHERE THE REQUIRED CLEARANCE WITH NO PROTECTION FROM APPLIANCE, VENT CONNECTOR, OR SINGLE WALL METAL PIPE IS: | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **36 inches** | | **18 inches** | | **12 inches** | | **9 inches** | | **6 inches** | |
| | **Allowable clearances with specified protection (Inches)[b]** | | | | | | | | | |
| | **Use column 1 for clearances above an appliance or horizontal connector. Use column 2 for clearances from an appliance, vertical connector and single-wall metal pipe.** | | | | | | | | | |
| | **Above column 1** | **Sides and rear column 2** | **Above column 1** | **Sides and rear column 2** | **Above column 1** | **Sides and rear column 2** | **Above column 1** | **Sides and rear column 2** | **Above column 1** | **Sides and rear column 2** |
| $^1/_2$-in. insulation board over 1-inch glass fiber or mineral wool batts | 24 | 18 | 12 | 9 | 9 | 6 | 6 | 5 | 4 | 3 |

For SI: 1 inch = 25.4 mm, 1 pound per cubic foot = 16.019 kg/m$^3$, °C = [(°F)-32/1.8], 1 Btu/(h × ft$^2$ × °F/in.) = 0.001442299 (W/cm$^2$ × °C/cm).

a. Reduction of clearances from combustible materials shall not interfere with combustion air, draft hood clearance and relief, and accessibility of servicing.
b. Clearances shall be measured from the surface of the heat producing appliance or equipment to the outer surface of the combustible material or combustible assembly.
c. Spacers and ties shall be of noncombustible material. No spacer or tie shall be used directly opposite appliance or connector.
d. Where all clearance reduction systems use a ventilated air space, adequate provision for air circulation shall be provided as described. (See Figures M1306.1 and M1306.2.)
e. There shall be at least 1 inch between clearance reduction systems and combustible walls and ceilings for reduction systems using ventilated air space.
f. If a wall protector is mounted on a single flat wall away from corners, adequate air circulation shall be permitted to be provided by leaving only the bottom and top edges or only the side and top edges open with at least a 1-inch air gap.
g. Mineral wool and glass fiber batts (blanket or board) shall have a minimum density of 8 pounds per cubic foot and a minimum melting point of 1,500°F.
h. Insulation material used as part of a clearance reduction system shall have a thermal conductivity of 1.0 Btu inch per square foot per hour °F or less. Insulation board shall be formed of noncombustible material.
i. There shall be at least 1 inch between the appliance and the protector. In no case shall the clearance between the appliance and the combustible surface be reduced below that allowed in this table.
j. All clearances and thicknesses are minimum; larger clearances and thicknesses are acceptable.
k. Listed single-wall connectors shall be permitted to be installed in accordance with the terms of their listing and the manufacturer's instructions.
l. For limitations on clearance reduction for solid-fuel-burning appliances see Section M1306.2.1.

### Electrical Building Structure Protection

Penetrations in fire resistance rated assemblies with electrical assemblies must be made so the risk of fire spread does not increase. Electrical penetrations must be protected by approves methods to maintain fire-resistance rating of the element penetrated per E3402.2 (*Penetrations of fire-resistance-rated assemblies).*

Penetrations in firestopping or draftstopping must be done so the integrity of the element is not compromised per E3402.3 (Penetrations of firestops and draftstops) do not apply because the house is not wood structure.

## Appendix 3.2: Code Narrative

**WPI Solar Decathlon Competition House**

**Fire Protection Narrative Report**

**Introduction**

Students and faculty at Worcester Polytechnic Institute (WPI) have teamed up with students and faculty at Ghent University in Belgium and New York University in New York to form the BMN (Belgium, Massachusetts, New York) Team for the Solar Decathlon China (SDC) 2013 competition (http://www.sdchina.org/). The design and construction of the house is required to follow both the SDC competition rules as well as the International Residential Code (IRC). The house is planned to be a one story single-family dwelling. The house is square, with a 36.9-foot (11.25 meters) long side length square shape, and a 258.334 square foot (24 square meter) closed atrium in the center. The total finished compliance area is 92 square meters, which includes two bedrooms, one “L-shape” living room, a kitchen and a technical room (see attached drawings). The design is unique for several reasons, particularly in the use of fiber reinforced polymer (FRP) panels with expanded polyurethane foam insulation. These panels, with the trade name Transonite, will be used to provide the structural system, roof and ceiling assemblies, and interior/exterior wall systems. Preliminary floor plans for the house are provided on subsequent pages.

The BMN house is new construction. As part of the competition, design, construction and occupancy is anticipated in four phases: Phase I - fabrication and testing of components; Phase II – temporary construction and occupancy in Worcester as a public exhibit (not for sleeping); Phase III – shipment to China for the SDC competition; and Phase IV – return to the USA with the potential for permanent siting in Worcester or the surrounding area.

To facilitate design, construction and occupancy of the building over the 4 phases, we are proposing permitting in three stages: Stage 1 – fabrication and testing as part of the research and development activity, where the fabrication and testing will occur one WPI premises and in a leased warehouse space (if needed); Stage 2 – temporary assembly for public viewing as an exhibit, ideally in Institute Park (temporary exhibition); and Stage 3 – as a permanent structure to be located in the Worcester area (occupancy).

As part of the Fire Narrative, reference will be made to information to be provided at the three stages of permit request as identified above. The narrative report complies with the Massachusetts Residential Code (MRC), which is the International Residential Code (IRC) with Massachusetts Amendments.

**Basis of Design**

**SECTION 1 - Building Description**

Use - Single Family Residential

Square Footage - 1361.61ft$^2$ (126.5m$^2$)

Roof – 7.45ft (2.27m) Atrium - 12.24ft (3.73m)

# floor above and below grade- 0

Hazards – None

Type of Construction – Fiber Reinforced Polymer (FRP panels)

**SECTION 2 – Building and Site Access**

The building and site access is governed by IRC R310, Emergency Escape and Rescue Openings.

**SECTION 3 – Applicable Laws, Regulations and Standards**

Massachusetts Residential Code 2011 (MRC)

R302 - Fire Resistant Construction

R310 - Emergency Escape and Rescue Opening

R311 - Means of Egress

R313 - Automatic Sprinkler Systems

R314 - Smoke Alarms

R315 - Carbon Monoxide Alarm

R316 - Foam Plastics

M2301 - Solar Energy Systems

**SECTION 4 – Design Responsibility for Fire Protection Systems**

The following people will be involved in the fire protection design.

Professor Brian Meacham, P.E., bmeacham@wpi.edu

Christian Lecorps, crchristianle@wpi.edu

Maria Del-Lourdes Gomez-Lara, gluglu75@wpi.edu

**SECTION 5 – Fire Protection Systems to be Installed**

**Water supply, fire mains and hydrants**

*As per MA amendments, automatic sprinkler system water supply requirements are governed by NFPA 13D*

**Automatic sprinkler system and components**

*Automatic sprinkler system requirements are governed by R313 of Massachusetts Residential Code (MRC).*

Aggregate area is less than 14400 square feet. Therefore, an automatic sprinkler system is not required according to MRC.

Automatic sprinkler system, if installed, shall be according to NFPA 13D

**Fire Alarm and Detection**

*Fire Alarm and smoke detection requirement is governed by R314 of Massachusetts Residential Code (MRC).*

Complete New System Required by Law

Smoke detectors are to be located per R314.3 in each bedroom, and outside each separate sleeping area in the vicinity of bedrooms

Smoke detectors must be interconnected according to R314.3 because the building has commercial power.

120V AC with battery backup

**Carbon Monoxide Alarms**

*Carbon Monoxide detection requirement is governed by R315.1 of Massachusetts Residential Code (MRC).*

Acknowledging that both carbon monoxide alarms and smoke detectors are required, we will provide a combination of smoke detector and carbon monoxide detector units.

Should be furnished, installed and maintained in accordance with M.G.L. c. 148 & 26 F 1/2, 527 CMR 31.00: Carbon Monoxide Alarm, 248 CMR. NFPA 720 and the manufacture's instruction

Carbon monoxide alarms are to be located outside the bedroom, within 10 feet to the bedroom door.

b. 120 V AC with battery backup

**Fire Extinguishers**

*Fire extinguishers requirement is governed by R329: Fire Extinguishers (USBC)*

One Type ABC fire extinguisher, size to be determined, to be located in the kitchen area.

**SECTION 6 – Design Methodology**

There are two specific areas for which we propose alternative designs: automatic sprinkler system and fire performance requirements of wall and ceiling materials. While we will meet the intent of NFPA 13D for the automatic fire sprinkler design, we plan to explore use of a mist system, which might also serve as part of the building cooling system. Since sprinklers are not required, we view this as an extra level of fire protection. Regarding fire performance of wall and ceiling material, based on the use of FRP material, which has not been tested to ASTM E84 or UL 723 (see below), we propose to undertake NFPA 286 room corner tests to assess performance relative to interior flame spread and thermal barrier performance. Design and testing is proposed to be conducted at WPI.

**SECTION 7 – Special Considerations**

This section serves to provide information relative to other fire-related aspects of the solar decathlon house that may not directly comply with the IRC. Most importantly, given the plan to use Transonite FRP Panels for structure, walls and ceilings, we would like to use alternative methods to comply with interior flame spread and thermal barrier requirements.

**WALLS AND PENETRATION**

Exterior Walls - the team BMN solar decathlon house does not need fire rated exterior walls because it has a fire separation distance greater than 5 feet (see Table R302.1).

Penetration Openings-Not required to be protected since it does not fall into category of 302.2 and 302.3.

Walls and Ceiling Finishes – required to be tested and approved in accordance with ASTM E84 or UL 723 as per IRC R302.9.4 (Alternate test method)

The Transonite panels, as a new material, have not been tested in accordance with ASTM E 84 or UL 723. As such, we plan to follow the route specified in the exception to IRC R302.9.4 to demonstrate equivalency.

Wall and Ceiling finishes will be tested using the Alternate test method in section R302.9.4, i.e., they will be tested in accordance with NFPA 286. Criteria for this test are:

During the 40 kW exposure, flames shall not spread to the ceiling.

During the 160 kW exposure, the interior finish shall comply with the following:

Flame shall not spread to the outer extremity of the sample on any wall or ceiling.

Flashover, as defined in NFPA 286, shall not occur.

The total smoke released throughout the NFPA 286 test shall not exceed 1,000 $m^2$

We propose to test the Transonite assembly with an intumescent fire protective coating.

We propose to conduct the tests in the Fire Laboratory at WPI, which is not an accredited laboratory.

A fire test and instrumentation plan will be provided.

**PARTITIONS**

Bamboo Partition Panels - the team BMN solar decathlon house is using bamboo panels are their partition material. Panels will be purchased and customized by Worcester Vocational High School.

The selected panels are FireGuard XL 95, which are Class A rated and have been tested in accordance with UL 723

**FOAM PLASTICS**

Insulation – Insulation is Foam Plastic which is required by IRC 302.9.3 to be tested and approved in accordance with ASTM E 84 or UL 723

Requirements by ASTM E-84 include

Documentation of compliance will be provided or we will follow the procedure outlined in the IRC R316.4 Thermal Barrier Exception

The Thermal Barrier shall be installed in such a manner that it will remain in place for 15 minutes based on NFPA 286 with the acceptance criteria of R302.9.4

We propose to use an intumescent coating on the Transonite panel to demonstrate equivalent performance. As noted above, the Transonite panel insulation assembly will be tested using the NFPA 286 room corner test

**EMERGENCY ESCAPE**

Sleeping rooms are equipped with one window (method of emergency escape) with dimensions per R310.1

**Testing Criteria**

This section outlines the procedure for inspection, testing and acceptance of the fire protection systems. This section contains the detailed information of personnel, methods and approvals.

**SECTION 1 – Testing Criteria and Methods**

Testing criteria and methods will be addressed with the Stage 2 and 3 permit applications.

**SECTION 2 – Testing Schedule**

Testing schedule will be addressed with the Stage 2 and 3 permit applications.

**SECTION 3 – Approvals**

Approvals will be obtained by Worcester Building Department and Worcester Fire Department following applicable requirements of the IRC with Massachusetts Amendments, including alternative methods and materials as outlined in this narrative.

## Appendix 4: Decision Rankings for both Cities

### Appendix 4.1: New York Decision Rankings

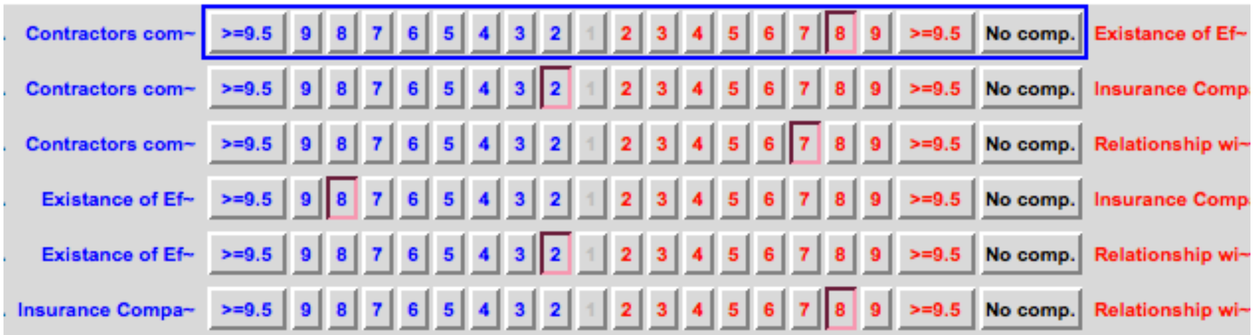
#### *Appendix 4.1.1: Upper Level*


Goals


Education


History


Regulatory




Social


Technology

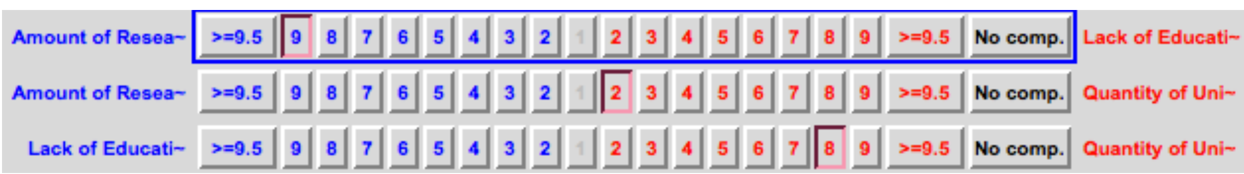
*Appendix 4.1.2: Lower Level (with respect to alternatives)*

| Level 2 Criteria | Performance Code | | | | | | | | | Prescriptive Code | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amount of Research | 9 | 8 | 7 | 6 | 5 | **4** | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Code Officials Outlook | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | **9** |
| Contractors Compatability with Prescriptive Code | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | **6** | 7 | 8 | 9 |
| Effects of 9/11 | 9 | 8 | 7 | **6** | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Existance of Effective Nonprofit Organizations | **9** | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| How Performance Based Codes Effect Fire Departments | 9 | 8 | 7 | 6 | 5 | 4 | 3 | **2** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Insurance Companies Benefits with Prescriptive Codes | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | **4** | 5 | 6 | 7 | 8 | 9 |
| Lack Of Education of the Code Officials | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | **9** |
| Level of Innovation in Current Buildings | **9** | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Quantity of Fire Labs Available for Testing and Research | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | **1** | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Quantity of Universities with Fire Protection Engineering | 9 | 8 | 7 | **6** | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Regional/General System Outlook | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | **9** |
| Relationship with Performance Based Fire Code Countries | 9 | **8** | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Results from Incidents | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | **4** | 5 | 6 | 7 | 8 | 9 |

## Appendix 4.2: Hong Kong Decision Rankings

### *Appendix 4.2.1: Upper Level*

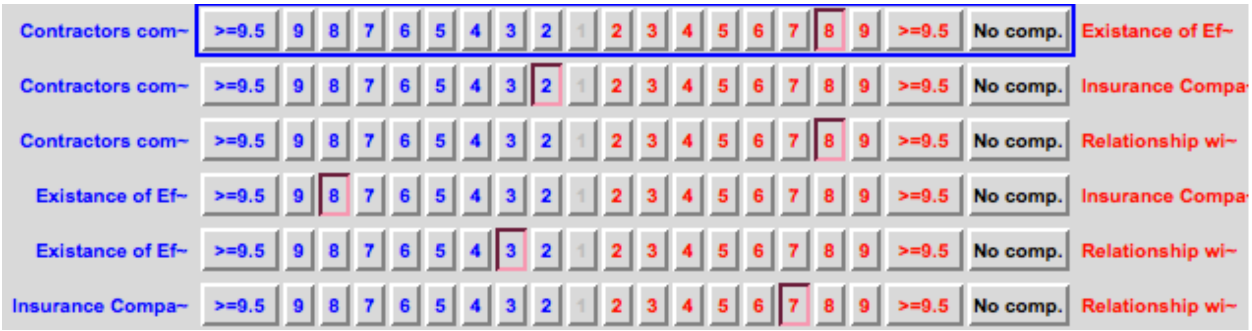

Goal



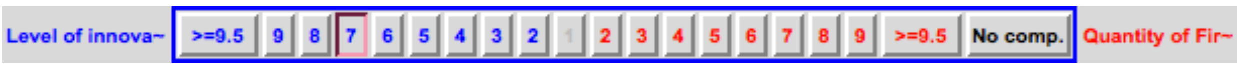

Education


History


Regulatory




Social



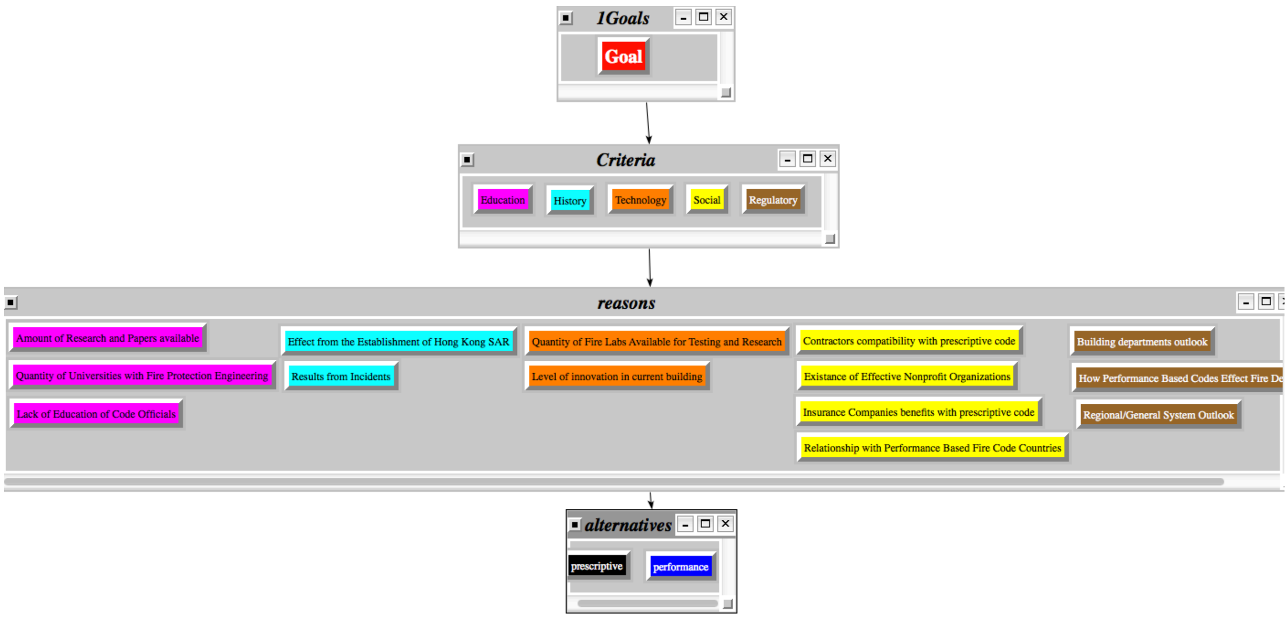

Technology

*Appendix 4.2.2: Lower Level (with respect to accelerators)*

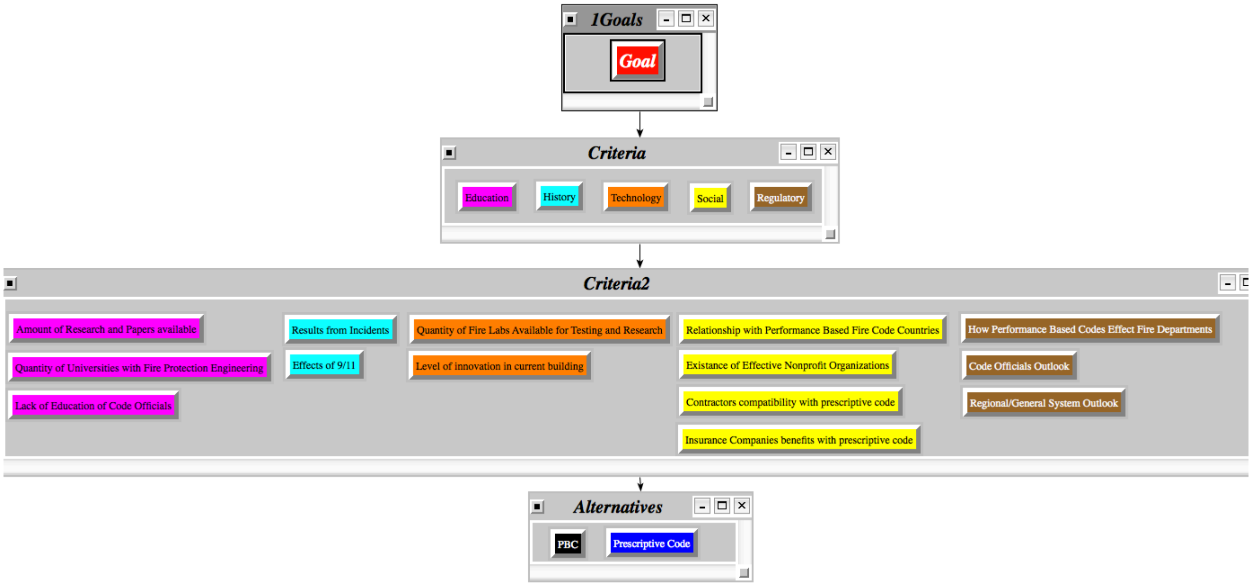
| Level 2 Criteria | Performance Code | | | | | | | | | Prescriptive Code | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amount of Research | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Code Officials Outlook | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Contractors Compatability with Prescriptive Code | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Effects of 9/11 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Existance of Effective Nonprofit Organizations | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| How Performance Based Codes Effect Fire Departments | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Insurance Companies Benefits with Prescriptive Codes | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Lack Of Education of the Code Officials | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Level of Innovation in Current Buildings | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Quantity of Fire Labs Available for Testing and Research | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Quantity of Universities with Fire Protection Engineering | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Regional/General System Outlook | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Relationship with Performance Based Fire Code Countries | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Results from Incidents | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

# Appendix 5: Full Decision Models

## Appendix 5.1: New York



## Appendix: 5.2: Hong Kong



# Appendix 6: Example of Portion of Table of Factors

| New York | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| History (3) | | | EPBFC (5) | | | Prescriptive Code (3) | | | Social Support (4) | | |
| **Factors** | **Relevancy** | **Rank 1 being most important/ overall rank out of 5** | **Factors** | **Relevancy** | **Rank 1 being most important/ overall rank out of 5** | **Factors** | **Relevancy** | **Rank 1 being most important/ overall rank out of 5** | **Factors** | **Relevancy** | **Rank 1 being most important/ overall rank out of 5** |
| World Trade Center | Could this be an incident in which they didnt think that drastically changing the code from a prescriptive code to a totally new code system was the correct idea, rather improving the current code would make people more comfortable | 1…5 | Case Studies | Buildings around the world that were taken into consideration that deemed performance based design unsafe compared to prescriptive. Could look at fire incidents in Performance Based building and see fire loss or fatalities involved. | 5…1 | Case Studies | Statistics of buildings around the world (IBC) not only NYC that deem prescriptive code safe doesnt make anyone feel it is necesary to change anything. | 2…3 | Current Society | Set up to better work with Prescriptive Code. Everyone understand Prescriptive Code and what has to be done. If it was switched to Performance Based Code an Engineer would have to work much closer with the contractors in order for the overall goal to get accomplished. | 2…4 |
| Case Studies | Buildings in New York City that had fire incidents either with performance based design or Prescriptive that were taken into consideration and made them not want to use performance based code | 2…3 | Less Protection | The fact that Performance Based Code relies on less fire components in certain areas could have been considered to scare people into thinking the building is not as safe because of this. | 4…2 | Safety | statisitics gathered that prove prescriptive code is already safe enough | 2…5 | non-profit organization to promote code change | similar examples can be found in New Zealand-a non profit orgnization pushed the code transition from prescriptive to PBC | 2…3 |

## Appendix 7: Classification for Burning Behavior of Building Materials and Products

# 建筑材料及制品燃烧性能分级

## 中华人民共和国国家标准

## 建筑材料及制品燃烧性能分级　GB 8624—2006（代替 GB 8624—1997）

**Classification for burning behavior of building**
**materials and products**

前 言

本标准是对 GB 8624—1997《建筑材料燃烧性能分级方法》的修订。
本标准代替 GB 8624—1997。本次修订是修改采用欧盟标准 EN 13501-1：2002《建筑制品和构件的火灾分级 第一部分：用对火反应试验数据的分级》（英文版）。其与 EN 13501-1：2002 的主要差异在于本标准除了全部采用 EN 13501-1：2002 规定的试验方法和等级划分外，对部分级别还规定了附加燃烧生成物的毒性试验要求。
本标准与 GB 8624—1997 相比有重大变化，其主要变化如下：
－在标准中对铺地材料和管道隔热材料的燃烧性能分级作了单独规定，燃烧性能等级由下标 fl 和 L 来分别区分；
—对材料燃烧性能级别的划分由 A 级（匀质材料）、A 级（复合夹芯材料）、B1、B2 和 B3 五个级别改为 A1、A2、B、C、D、E、F 或 A1fl、A2 fl、B fl、C fl、D fl、E fl 、F fl 七个级别；
—对材料燃烧性能级别判定所用的试验方法以及判据有大的变化，特别是考虑了燃烧的热值、火灾发展速率、烟气产生率等燃烧特性要素；
—燃烧性能分级适用的材料范围有所变化，对原标准规定的部分特定用途的材料，如窗帘幕布类纺织物、电线电缆套管类塑料材料的分级不再包括。
本标准的附录 C 为规范性附录，附录 A、附录 B 为资料性附录。
本标准由中华人民共和国公安部提出。
本标准由全国消防标准化技术委员会第七技术委员会归口。
本标准历次版本发布情况为：
——GB 8624—1988、GB 8624—1997。
引 言

GB 8624 于 1988 年首次发布，其后参照西德标准 DIN 4102-1：1981《建筑材料和构件的火灾特性 第一部分：建筑材料分级的要求和试验》，对其进行修订，发布了修订版 GB 8624—1997。该标准在实施的十多年中，作为我国建筑材料及建筑物内部使用的部分特定用途材料燃烧性能分级的准则，对进行材料防火性能评价、指导防火安全设计、实施消防安全监督、执行防火设计规范发挥了重要作用，产生了显著的社会经济效益。
随着欧盟的成立，2002 年欧盟标准委员会（EN）制定并颁布了欧盟统一的材料燃烧性能分级标准，即 EN 13501-1：2002 《建筑制品和构件的火灾分级 第一部分：用对火反应试验数据的分级》，以此统一了建筑制品对火反应燃烧性能分级的程序。该标准实施后，欧盟成员国原各自的材料分级标准（包括 DIN 4102-1）同时废止。也就是说现行的 GB 8624-1997 标准依据的国外标准已不复存在。EN 13501 是一个系列标准，它的第二、三、四部分是通过耐火试验确定分级的方法，第五部分是关于外部火焰屋顶试验确定分级的方法。
随着火灾科学和消防工程学科领域研究的不断深入和发展，对燃烧特性的内涵也从单纯的火焰传播和蔓延，扩展到包括燃烧热释放速率、燃烧热释放量、燃烧烟密度以及燃烧产物毒性等参数。而 EN 13501-1 的分