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Bridging the knowledge gap between fire engineers and building service engineers - Using the Analytic Hierarchy Process approach

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Abstract

Architects are confronted with the priority of the early integration of natural smoke ventilation (NSV) and natural thermal ventilation (NTV) objectives in retail building designs due to several reasons including wide range of expertise and lack of fire safety knowledge. This paper presents the perception of fire engineers (FE) and building service engineers (BSE) regarding the conceptual priorities of the early integration for particular design decisions. This was achieved through surveying FE and BSE and conducting an analytical study using the Analytic Hierarchy Process (AHP) technique. An experts' panel was held for each profession for confirmation. The results showed that FE and BSE have agreed on the most and least crucial design decisions that should/shouldn't require integration of NSV and NTV objectives in the early stages of the architectural design process.

Keywords: Architecture design decisions, Early integration, natural smoke ventilation, Analytic Hierarchy Process.

1. Introduction

The architectural design is a multi-disciplinary process that requires coordinated contribution from all disciplines involved. Architects are responsible of incorporating the design strategies of all disciplines and systems compatibly at some stages in the design. More attention should be given to the interacting systems in order to avoid conflict in the performance. This paper discusses the importance of the early integration of the objectives of two interacting systems, Natural Smoke Ventilations (NSV) and Natural Thermal Ventilation (NTV) in the design of retail

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buildings. Those two interacting and intertwining systems have different design objectives, however; both are impacted by the same architectural design decisions as both systems use the same path

No doubt that the architectural design and the other design strategies of different systems in building impinge each other. Therefore, integrating and incorporating these design strategies compatibly at some stages in the design is essential to improve building's performance efficiency. Thermal and smoke ventilation systems are two significantly crucial systems that are designed to achieve different objectives such as providing thermal comfort and good indoor air quality, and providing clear/smoke-free layer to allow evacuation and facilitate fire-fighting operations. The British codes and standards have regulated building ventilation and smoke control explicitly in different documents -e.g. BS 9999 [1], Approved documents [2], BS 7346-4 [3], BS 5925 [4]- of which architects must meet. However, fire safety, more specifically smoke control, is not always considered seriously in the designs of buildings, for many reasons [5, 6, 7], including lack of understanding and cooperation between fire engineers and architects, the difficulty and complexity of using the fire codes by architects, and/or expensive costs of fire safety installation especially what is considered not vital because it is not "every day-use" and used only "in case of fire".

Integrating the design objectives of these systems in the design process requires adequate level of understanding and solid communication among the parties involved that allow them to speak a common language. Knowing when to integrate the design strategies of any discipline in the architectural design is so critical that it could impact the effectiveness of the whole building design. Moreover, it could help to avoid spending extra time and/or money that result from late integration or unnecessary early integration of the design strategies. With regard to natural thermal ventilation (NTV) and natural smoke ventilation (NSV), there are two possible scenarios to integrate the objectives of those two systems in the architectural design process. The late integration means that NSV design is developed and tested after completing the architectural design drawings, and "added" to the design to get authority approval. The early integration means that NSV is considered, developed and tested in the early stages in the design with NTV. Architects' decisions related to fire considerations could be driven by cost, size, nature, complexity of the project, and/or lack of awareness of the early integration approach. Therefore, sometimes they give more priority to the design considerations of building ventilation system than fire safety system, as the later system is not an "everyday" use. As a result, fire safety is not properly considered in the architectural designs, more importantly, not early enough to be part of the design rather than being an "add-on". The term "early" in the context of this study means that fire safety is considered in the decision-making process and before the decision-taking process.

This research is a step towards bridging the knowledge gap between architects and fire engineers through guiding architects to properly integrate fire safety objectives in their designs.

2. Literature Review

2.1. Architects' knowledge

No doubt that architects' knowledge is reflected in their design activities. Architects' decisions are based on two basic sources: theoretical knowledge and practical experience [8]. For the last five decades, there have been continuous efforts to base architecture on scientific foundation. More details on the problem of transferring the scientific knowledge to the architectural education are provided in [9, 10, 11, 12]. The purpose of investigating the problem of transferring scientific knowledge is to decrease the gap between both academic and practice architects. This problem is attributed to several reasons including (i) the personnel differences in perceiving knowledge and experience from design activities [13], (ii) lack of common language between both sides regarding expressing their needs, and (iii) negativity in designers' attitude when it comes to scientific information [14]. Practice architects will have positive attitude towards information sources if it is perceived in architectural terms [12]. The lack of this type of knowledge, more specifically fire safety related, is missing from the architecture education. This is clear in the architectural curriculum in the UK (RIBA Core Curriculum leaflet: syllabus of the RIBA Parts 1, 2 and 3). The syllabus doesn't show any courses for fire engineering fundamentals. The architect as a lead designer in the team is responsible to deliver comfortable and healthy environment, while safe in the meantime. The right timing for integration design strategies of other systems improves the efficiency of the design, and assures the implementation of life safety measures.

2.2. Integration of Fire safety objectives in the architectural design

In the early 1980s, the integration approach was discussed with regard to fire safety objectives in the architectural design. Fire safety is one of many objectives to be achieved and fulfilled in the architectural design process. Integrating fire safety objectives in the architectural design could increase the quality of the architectural and fire design [7]. On the other hand, not considering it in early stages of the design could affect the quality of the fire safety system [15]. In fact, architects can't go on with their sketch plans until fire problems are resolved. However, meeting the fire safety requirements in buildings is not the responsibility of the FE alone or the architect alone; it is the responsibility of both of them. Same with the thermal comfort, it is the responsibility of both BSE and architect. It is essential to consider fire safety with ventilation at early stage of the design to benefit from "dual-purpose system" evaluation [16]. Building natural thermal ventilation is designed to achieve objectives that are different from the ones for natural smoke ventilation. However, the two systems can be incorporated compatibly at some stages of the design. This was emphasized in the CIBSE Application Manual AM10 [17] that natural ventilation strategy must be integrated with smoke ventilation strategy since both follow the same path. The British Standards 7346-5 [18] advise the smoke ventilation designer to consider any potential interaction with other systems to avoid conflict in operating and to achieve the optimum of the design. Considering ventilation system design into smoke control design and investigating both simultaneously offer significant contributions to the performance of both [19]. For example, natural ventilation could offer duel benefit in smoke control design if well considered. This could be designed through installing louvered ventilators (vertically or horizontally blades) that provide day-to-day thermal comfort and smoke control ventilation in the same time [20]. Integration was also emphasized in the BRE 375 report [19] indicating that strategies of natural smoke ventilation and natural building ventilation "in principle" can be combined effectively if designed with the integrated approach at early stage of the design. However, if left to later stages can result in more costs and less performance efficiency. This report emphasizes that the design must be compatible with the smoke ventilation objectives to allow efficient smoke extraction.

2.3. Design criteria of Natural Smoke Ventilation (NSV)

Shopping building is one of building types that have been greatly influenced by the advanced technology. With the elevated complexity in shopping malls and the increasing trend towards adopting large void spaces, architects face many challenges to meet building and fire codes. In the context of this study, the term "shopping mall" refers to an enclosed multi-story (2-5 stories) shopping building with atrium space, unless otherwise mentioned. Managing smoke movement in large buildings with atria and covered mall is a challenging task, where smoke spreads fast. The criticality of shopping buildings is due to the fact that it usually contains large enclosed spaces with no physical separation between atria and interconnecting spaces resulting in smoke spreading [21], the large number of people evacuating at the same time who are not familiar with the building; wide variety of occupants include disabled, children and elderly, and massive fire load. In such buildings, it would be difficult to evacuate the building in short time.

Atrium is a major concern for architects, fire engineers, and building service engineers. With regard to thermal comfort, atrium types may be classified based on their objectives, warming, cooling, and convertible atria. The warming atrium would allow air circulation in the atrium space driven by stack effect, and it is recommended to plan for reservoir at the top of the atrium space to allow warm air to be collected to increase thermal comfort. On the other hand, the cooling atrium would be designed to store cool air using stack effect and cross ventilation strategies. Hence, atrium is considered as part of the ventilation system in the building [15]. And since stack effect is one of the main natural forces driving smoke through upward movement of gases within building shafts, it is crucial not to integrate and coordinate between NTV and NSV systems.

Developing a fire design for a shopping mall is basically assessing the potential level of hazard by predicting fire behavior, and smoke movement and spread to the interconnecting space. This is to be carried on through assessing some physical parameters (e.g. position of the smoke layer base, temperature, concentration of carbon monoxide) based on engineering principles [21]. The British Standard [3] emphasized that designers should define the design criterion or the purpose of the design clearly whether it is for protecting escape routes, protecting property, controlling temperature, facilitating fire-fighting operation, or combination of any. The main principle in a smoke control system design is to avoid being overpowered by the forces driving smoke.

3. Research methodology

This study is carried out via three stages; (i) design and structure an AHP model to assess engineers priorities with regard to the early integration of NSV and NTV objectives in retail buildings design, (ii) surveying professionals in fire and building service engineering using AHP technique to collect their judgments regarding prioritizing the architectural design decisions with respect to the importance of early integration of NSV/NTV objectives (iii) surveying experts in fire and building service engineering to confirm and validate the engineers' judgments and priorities and assure comprehensibility. A pilot study was conducted prior to the AHP survey to test and refine the questionnaire aiming a variety of engineers in the industry, academia, and consultancy career.

The architectural design decisions influencing naturally-driven flow of air and smoke have been derived from an extensive review of literature including experimental and numerical research, British regulations, and related governmental documents. There are seven architectural design decisions that have been identified, which affect natural air and smoke flow. Those design decisions to be assessed with regard to early integration of NSV and NTV are: building geometry, building façade, interior and construction material (in the context of thermal impact), opening characteristics, opening orientation, space profile, and landscaping and adjacent buildings [22]. In order to have accurate and reliable assessment for FE' and BSE' perception regarding the early integration priority of NSV and NTV objectives, it was necessary to refine and confirm the priorities of both ventilation systems with regard to those seven design decisions. This was done by forming an experts' panel of fire engineers (FE) and building service engineers (BSE) seeking the opinion.

3.1. Assessing engineers 'priorities for the early integration of NSV and NTV- AHP survey

In order to gauge FE' and BSE' perception for early integration priorities of NSV and NTV with respect to the selected design decisions, the AHP approach was used. The AHP is a multi-criteria decision making (MCDM) tool that allows assessing qualitative alternatives quantitatively with high consistency in judgment via assigning numerical weights. It derives penetrating insights and reflects mental visions through assigning weights that are based on logical and analytical understanding by participants [23]. The AHP helps to view the interaction among elements vertically and horizontally through all levels of the hierarchy. It incorporates the qualitative and quantitative aspects through defining and understanding the hierarchy problem, and providing judgments via paired comparisons. This incorporation helps to select the most preferred alternative among different alternatives [23]. The development of an AHP model can be described in four steps [24]:

- Construct hierarchy/questionnaire (establish your decision making problem in a hierarchal order);
- Establish priorities (do the pair-wise comparisons through comparing the preference of every two elements of the hierarchy in any given level);
- Check consistency (quantify weights of the elements, calculate eigenvector, eigenvalue, then consistency ratio); and
- Combine (synthesize) weightings.

In order to structure a hierarchy, the problem must be broken down into a number of levels. In this study, the hierarchy model consists of three levels starting with the goal (prioritization of the criticality of early integration of NSV and NTV

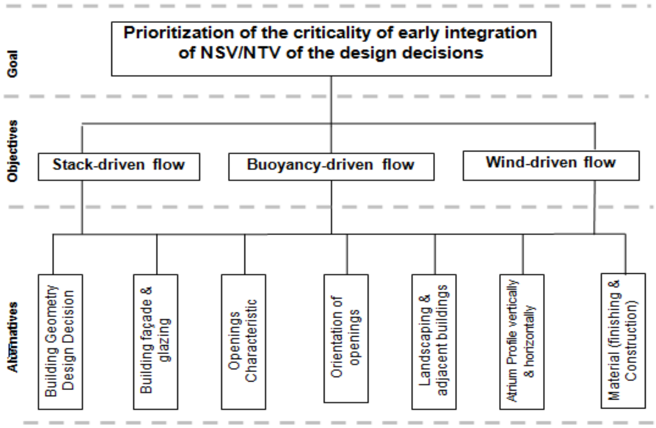

Figure 1. AHP Model for assessing Engineers priorities

objectives in the architectural design decisions) at the top of the hierarchy, which is decomposed to the objectives in the second level of the hierarchy (the three main driving forces). The objectives connect the alternatives (the selected design decisions) in the third level of the hierarchy at the bottom with the goal at the top, as shown in **Figure 1**. Every element in the hierarchy is being assessed using the pair-wise comparisons judgments with respect to each element in the level immediately above in the hierarchy. The pair-wise comparison judgments are based on assigning relative weights to the hierarchy elements using a scale from 1-9, where 1 is the least important, and 9 is the most important. The nine values in Saaty-scale represent the intensities of judgments, and it is an evidence of favouring one activity over another in the highest possible order of affirmation [23]. The assessments of the elements in any level of the hierarchy with respect to any element in the level above are expressed in a ratio forming a matrix, where each matrix represents a decision.

3.2. Fire Engineers and Building Service Engineers perceptions

The AHP survey was designed for FEs' and BSEs' aiming to assess their prioritization of the architectural design decisions in terms of the imperativeness of the early integration of NSV and NTV objectives in the design process. To fulfill this aim, judgments of experienced engineers are collected and synthesized. In order to test the clarity of AHP questionnaire, refine the questionnaires' structure, and validate the rationality and coherence of questions before distribution, a draft copy of the questionnaire is piloted to obtain feedback from FE and BSE. Draft copy was sent to 15 FE and 15 BSE participants from industry, academic, and code consultancy.

Selecting the target responder is a very critical step to avoid arbitrary opinions and misled results. Careful selection is essential in order to receive more rigorously results. The criteria set for engineers' target responders were to have at least one of the following criteria:

1. Work experience in NSV/NTV design generally, for FE/BSE respectively.
2. Work experience in NSV/NTV design at retail buildings, for FE/BSE respectively.
3. Academic experience with interest of NSV/NTV design.

Finding responder with those specific criteria was a challenging task. A database was developed to cover different cities and universities within the UK. Contact was made with 150 FE, and 150 BSE from industry, academia, consultancy, and governmental sectors (Code developer). This diversity was planned to receive robust results, and increase credibility. Experts were selected from the engineering panel based on having two of the criteria above, in addition to the "7+ years" of experience. From the personal contact with participants, 10 fire engineers and 7 building service engineers met the experts' criteria and agreed on participating. The purpose of seeking experts' opinion is to validate and add credibility to results.

Based on the hierarchy model developed, a questionnaire was designed using the Expert Choice Comparion™. The Expert-Choice Comparion™ is web-based software. Questions were designed on the basis of "pair-wise comparison". Participants were asked to provide their judgments by assigning relative weights to the hierarchy elements using a scale from 1-9. However, it is very important to note that these priorities don't indicate that some design decisions are more important than others, but rather highlight that early integration of NSV/NTV objectives is more important for some decisions than others. This hierarchy model would result in 4 matrices for each responder. The first matrix is to assess the relative importance of each driving force with respect to the goal. The first matrix asking in pairs: which of the driving force is more important with respect to early integration of NSV objectives (for FE), or NTV objectives (for BSE) in the decision making? The assessment was based on the impact of each natural driving force on air and smoke movement. The other three matrices ask in pairs: which of the seven design decisions is more important for early integration of NSV/NTV with respect to each driving force?

4. Results and discussion

Using the Expert Choice Program, the FE and BSE judgments were pair-wise compared and their matrices were calculated to give local and global priorities. The local priority (LP) weights represent the relative importance of any objective or alternative with respect to their 'parents' in the level immediately above. And the global priority represents the relative importance of any objective or alternative with respect to the goal of the hierarchy. The higher the weight of local/global priority, the greater the relative importance is. The normalized sum of the local or global priorities for all elements in the same level must equal one.

4.1. Fire Engineers Questionnaire- professional and expert panels

Table 1. Overall Priorities of design decisions by FE 'designers'

Alternative	Stack (0.184) LP	Buoyancy (0.502) LP	Wind (0.314) LP	Final Priority GP	Overall Ranking
Geometry	0.161	0.162	0.142	**0.155**	**4**
Façade	0.10	0.079	0.056	0.076	**6**
Opening	0.242	0.226	0.218	**0.227**	**1**
Orientation	0.139	0.119	0.27	**0.168**	**3**
Landscaping	0.067	0.064	0.193	0.105	**5**
Atrium profile	0.222	0.261	0.085	**0.2**	**2**
Material	0.069	0.089	0.036	0.069	**7**

As perceived by fire engineering designers, results showed that they consider buoyancy-driven flow the most crucial with GP of (0.502) among the natural driving forces with respect to early integration of NSV objectives in the design process. Wind-driven flow was the second crucial (0.314), and stack-driven flow was the least crucial (0.184). With respect to stack effect, results showed that FE gives more priority to 'opening characteristics' and 'space profile' for early consideration of smoke ventilation objectives. With respect to buoyancy effect, results show that 'space profile' and 'opening characteristics' are again the most crucial design decisions that require early integration of NSV objectives. It can be noticed that priorities of the design elements with respect to both stack and buoyancy are very similar, but only 'material of interior and construction' and 'façade and glazing' were oppositely ranked. However, these two design elements specifically were given very similar weight with respect to the two driving forces. And with respect to wind effect, results show that 'orientation' is considered the most crucial design element that requires early integration of NSV objectives. It can be noticed that priorities of the design elements with respect to wind are very different from the ones with respect to stack and buoyancy effects.

The FE overall ranking results illustrated in **Table 1** show that with respect to the three natural driving forces, and with (0.00) overall inconsistency in judgements the four design decisions of 'opening characteristics' with GP of (0.227), 'space profile' (0.200), 'orientation' (0.168) and 'geometry' (0.155) have more priority for early integration of NSV objectives. However, the decisions of 'landscaping and adjacent buildings', 'façade and glazing' and 'material of interior and construction' have less priority.

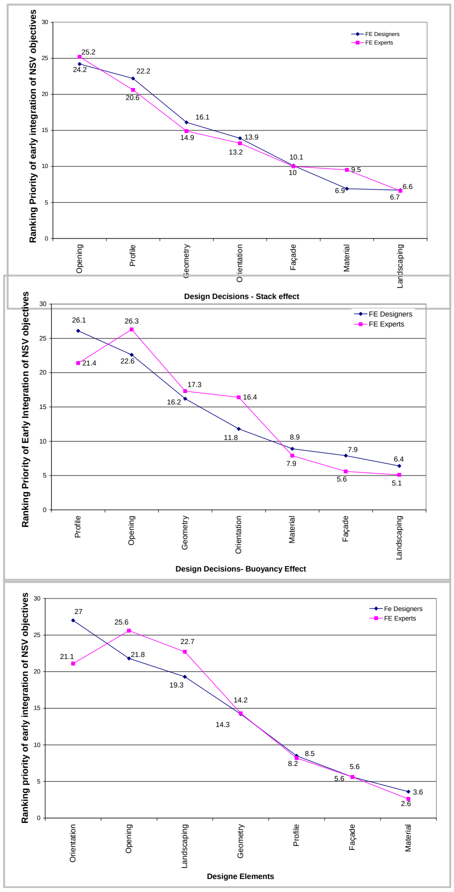

Figure 2- FE experts vs. designers – Stack, Buoyancy, and Wind effect

With regard to the experts' panel, The FE experts ranked the three natural forces with typical ranking priority as the FE designers, and very slight differences in weighting values, **Figure 2**. With respect to each driving force, experts' ranking priorities for the seven architectural design decisions regarding the early integration of NSV objectives was very similar to the designers' ranking. With respect to stack, experts gave identical ranking with very similar priority values. Experts ranked some decisions slightly higher than FE designers (e.g. opening characteristics, material of interior and construction), and others slightly lower (e.g. atrium profile, geometry, orientation, façade and glazing, landscaping and adjacent buildings). Experts' judgements support the FE designers' priorities with respect to stack effect, and add rigorousness to the ranking of the design decisions. With respect to buoyancy effect, experts perceive 'opening characteristics' and 'profile' as the two most crucial design decisions. However, differently from designers, they considered the former decision more important than the later. With respect to wind-effect, FE experts have perceived that ‘opening’, ‘landscaping’ and ‘orientation’ are the three most crucial design decisions. This priority ranking was different from the designers (orientation, opening and landscaping, respectively). However, the remaining design elements were not only similarly ranked, but also had almost the exact values.

4.2. Building Service Engineers Questionnaire- professional and expert panels

In building service engineering perception, results show that they consider wind-driven flow as the most crucial among the three natural driving forces with a GP of (0.379) with respect to early integration of NTV objectives in the design. They also consider stack the second crucial (0.312), and buoyancy-driven flow the least crucial (0.310). Differently from FE, the differences among the driving forces are insignificant. This indicates that in BSE understanding the wind-driven flow is considered slightly more crucial than stack and buoyancy. The considerable difference between the most and least crucial driving forces in FE perception compared to BSE perception could be due to the significant difference in the temperature of smoky gases and airflow. With respect to stack-effect, results show that ‘opening characteristics’, ‘profile’ and ‘geometry’ are the most crucial decisions in terms of the imperativeness of early integration of NTV objectives. With respect to buoyancy-effect, results show that ‘geometry’, and ‘profile’ are the most crucial for early integration of NTV objectives based on their great impact on airflow driven by buoyancy. And with respect to wind effect, results show that BSE perceive ‘orientation’, ‘landscaping and adjacent buildings’ and ‘opening characteristics’ decisions as the most crucial with respect to the influence on airflow patterns.

Table 2. Overall Priorities of design decisions by BSE ‘designers’

Alternative	Stack (0.312) LP	Buoyancy (0.310) LP	Wind (0.379) LP	Final Priority GP	Overall Ranking
Geometry	0.180	0.257	0.144	**0.192**	**1**
Façade	0.109	0.132	0.057	0.099	**6**
Opening	0.243	0.130	0.168	**0.181**	**3**
Orientation	0.150	0.112	0.289	**0.186**	**2**
Landscaping	0.074	0.056	0.187	0.107	**5**
Atrium profile	0.187	0.22	0.114	**0.172**	**4**
Material	0.057	0.093	0.041	0.063	**7**

The BSE overall ranking results illustrated in **Table 2** show that with respect to the three natural driving forces, the decision of ‘geometry’ with GP of (0.192), ‘orientation’ (0.186), ‘opening characteristics’ (0.181) and ‘profile’ (17.2) are the most crucial ones with respect to the early integration of NTV objectives. However, the decisions of ‘landscaping’, (0.107), ‘façade’ (0.099) and ‘material’ (0.063) are significantly lower in the priority.

With regard to the experts’ panel, the BSE experts ranked the three natural forces similarly to the designers’ ranking order, **Figure 3**. Experts considered wind-effect the most crucial with respect to early integration of NTV objectives in the design, with a GP of (0.431). Wind-effect priority is nearly 1.5 times more important than stack-effect and buoyancy-effect. Comparing experts’ opinion and designers’, both have equal importance for stack-effect and buoyancy effect, and similar ranking for the three forces. With respect to stack, experts perceive ‘opening characteristics’ as the most important with respect to the early integration of NTV objectives in the design with a GP of (0.250), and ‘profile’ the second crucial (0.235). Then, ‘orientation’ and ‘geometry decisions were perceived slightly less important than the two most crucial. And, ‘landscaping’, ‘façade’, and ‘material’ were the very least important. With respect to buoyancy effect,

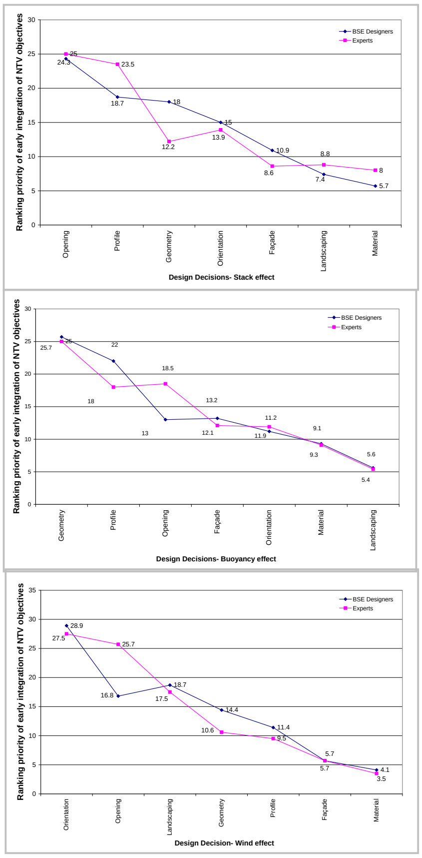

Figure 3- BSE experts vs. designers – Stack, Buoyancy, and Wind effect

experts perceive 'geometry' the most crucial design decision with a GP of (0.250), followed by 'opening' and 'profile' with a very similar GP (0.180) and (0.185). The 'façade' and 'orientation' decisions had very similar GP; however, lower than the former decisions. The 'Material' and 'landscaping' decisions had the least priority (0.091) and (0.051), respectively. With respect to wind effect, the most influencing air movement, BSE experts perceive 'orientation' with GP of (0.270), 'opening' (0.257) and 'landscaping' (0.175) the three most crucial design decisions. The BSE experts' overall ranking of the seven design elements, with respect to the three natural forces, shows that with (0.0009) overall inconsistency in judgments the decisions of 'openings', 'orientation', 'profile' and 'geometry' are the four most crucial design decisions. These decisions require early integration of NTV objectives in the design. However, the decisions of 'landscaping', 'façade' and material are the least important.

5. Conclusions

The results show that fire engineers (FE) and building services engineers (BSE) perceive the importance of the natural driving forces differently. However, they have very similar priorities for the design decisions with respect to the early integration of NSV and NTV objectives, as explained in the following:

1. Fire Engineers consider buoyancy-effect the most critical, with regard to early consideration of NSV, with significant difference compared to wind-effect and stack-effect.
2. Building service engineers consider wind effect the most critical, with regard to early consideration of NTV, with slight difference compared to stack-effect and wind-effect.
3. The decisions of 'opening', 'profile', 'orientation' and 'geometry' are the four most crucial decisions in the perception of fire engineers and building services engineers with respect to the early integration of NSV objectives and NTV objectives. While the decisions related to 'landscaping', 'façade' and 'material' are the least important in the perception of both FE and BSE. This indicates that these decisions may not be crucial for early integration.
4. Fire engineering experts and designers have the same perception of the ranking priorities of early integration of NSV objectives of the decision with respect to stack, buoyancy, and wind.
5. Building Service engineering experts and designers had agreed on the priority of 'orientation', 'landscaping', 'façade', and 'material', while disagreed on the priority of 'geometry', 'opening', and 'profile' in their perception of the early integration of NTV objectives with respect to the natural driving forces.

It is interesting to note that despite NSV and NTV designs have different objectives; both FEs and BSEs had the same perception for the most and the least crucial decisions. This finding highlights the criticality of the most crucial decisions. Corresponding to this finding, architects must adopt NSV objectives of the four most crucial design decisions at early stage in the design as equal as they do with NTV objectives.

References

[1] BS 9999. Code of practice for fire safety in the design, management and use of buildings, British Standards Institute, 2008.

[2] Approved Document B. Approved Document B (Fire safety) – Volume 1: Dwelling houses, Communities and Local Government, 2006.

[3] BS 7346-4. Components for smoke and heat control systems- Functional recommendations and calculation methods for smoke and heat exhaust ventilation systems, employing steady-state design fires -Code of practice, British Standard Institute, 2003.

[4] BS 5925. Code of Practice for Ventilation Principles and Designing for Natural Ventilation, British Standard Institute, 1991.

[5] J.G. Quintiere, Fire behavior in building compartments, Proceedings of the Combustion Institute, 29 (2002) 181-193.

[6] D.C.J. Peters, HVAC systems for the fire protection engineer, Fire Safety Journal, 7 (1984) 65-80.

[7] P. Stollard, The integration of the objectives of fire safety into the process of architectural design, PhD thesis. Oxford Polytechnic, UK, 1986.

[8] R. Rambow & R. Bromme, Implicit psychological concepts in architects' knowledge - How large is a large room? Learning and Instruction, 5 (1995) 337-355.
[9] M. Mackinder & H. Marvin, Design Decision Making in Architectural Practice, Institute of Advanced Architectural Studies, University of York, 1982.
[10] T.A. Markus & D. Cameron, The words between the spaces: buildings and language, Routledge, 0 415 14345 4, 2002.
[11] K. Dorst, Design research: a revolution-waiting-to-happen, Design Studies, 29 (2008) 4-11.
[12] J.A. Powell, Is architectural design a trivial pursuit? Design Studies, 8 (1987) 187-206.
[13] L. Carvalho, A. Dong & K. Maton, Legitimating design: a sociology of knowledge account of the field, Design Studies, 30 (2009) 483-502.
[14] F.H. Sancar, Behavioural knowledge integration in the design studio: an experimental evaluation of three strategies, Design Studies, 17 (1996) 131-163.
[15] R. Saxon, Atrium Buildings: Development and Design, Second ed., The Architectural Press, London, 1986.
[16] CIBSE-Guide B, Heating, Ventilating, Air Conditioning and Refrigeration, CIBSE, London, 2005.
[17] CIBSE-AM10, Natural Ventilation in non- domestic buildings, CIBSE, London, 2005.
[18] BS 7346-5, Components for smoke and heat control systems- Functional recommendations and calculation methods for smoke and heat exhaust ventilation systems, employing time-dependent design fire, British Standard Institute, 2005.
[19] C. Williams, E. Perera & H. Morgan, Natural ventilation in atria for environment and smoke control-An introductory guide, BRE 375, Building Research Establishment, London, UK, 1999.
[20] Colt, Smoke Control in Shopping Centres. Colt International Limited, 2008. Available at: http://www.coltinfo.co.uk/files/pdf/UK/Smoke%20control%20in%20shopping%20centres.pdf .
[21] J.A. Milke, Smoke Management in Covered Malls and Atria, in: SFPE Handbook of Fire Protection Engineering, third ed., National Fire Protection Association, Massachusetts, 2002, pp. (4-292)-(4-310).
[22] R. Doheim, Towards an Architectural Strategy for Early Integration of Natural Smoke Ventilation in Retail Buildings, Ph.D. Thesis, University of Ulster, UK, 2012.
[23] T.L. Saaty, Decision making for leaders: the analytic hierarchy process for decisions in a complex world, RWS publications, 1988.
[24] T.L. Saaty & L.G. Vargas, Models, Methods, Concepts and Applications of the Analytic Hierarchy Process, Kluwer Academic Publishers, Boston/ Dordrecht/ London, 2001.