Building technology research in architectural practice:
emerging trends

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ABSTRACT:

This paper discusses relationships between research, architectural design and technology with particular focus on the descriptions and activities of a practice-oriented architectural research program. The objectives of the program are to advance the performance of project designs, improve the decision-making process and to inspire innovation through systematic investigations of building performance and emerging building technologies. First, descriptions of the research program are discussed, such as research objectives and methodologies. Then, two case studies are reviewed that show relationships between architectural design and conducted research, illustrating how research results inform design decisions. The first case study focuses on the investigation of thermal comfort and exterior design elements for courtyard design. The second case study investigates energy consumption studies in relation to façade design.

CONFERENCE THEME: "On Relevance": Identifying emerging trends in architectural research
KEYWORDS: building technology research, architectural practice, building performance, innovation

INTRODUCTION

This paper discusses relationships between research, architectural design and building technology. These following themes are discussed:

- Development of a research program that supports objectives and the vision of a global architectural practice
- Relationships between architectural design and building technology research and how research influences design outcomes.

This paper is structured in the following way: first, an overview of practice-oriented building technology laboratory is presented, which is a part of a leading architectural design firm. Research objectives and studies are determined by the needs of architectural projects. Then, relationships between research and architectural projects are discussed and how research results are used for the decision-making process. Two case studies are presented, one focusing on thermal comfort and outdoor design elements and the second one focusing on façade energy studies.

1. BUILDING TECHNOLOGY RESEARCH AND ARCHITECATURAL PRACTICE

1.1. OVERVIEW OF TECH LAB

Building Technology Laboratory (or "Tech Lab") is an on-going research program at Perkins+Will. The research objectives are to monitor developments in building systems, materials and information technology; review and analyze emerging technologies that can have a direct impact on the course of architectural design; and investigate building systems and technologies that can significantly improve the value, quality and performance of architectural projects (Aksamija 2009; Aksamija 2010).

The operation of Tech Lab is portrayed in Figure 1, illustrating major concepts that relate to the conducted research and dissemination of results:

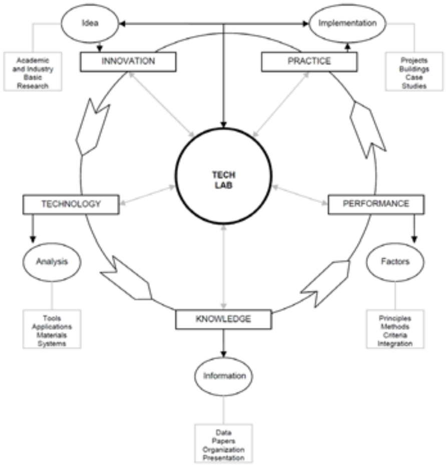


Figure 1: Research objectives and methods.

- *Innovation* refers to basic research and monitoring of developments in building systems, materials and information technology to document emerging technologies.
- *Technology* refers to investigations and technical analyses that are conducted for specific architectural projects focusing on energy performance, daylighting studies and investigation of thermal behavior.
- *Knowledge* refers to collecting information, publishing research results and organizing information databases, presentations and seminars aimed to disseminate research results.
- *Performance* and *Practice* refer to implementation of research findings on architectural projects.

1.2. KNOWLEDGE DISSEMINATION OF RESULTS

Research results are shared internally as well as with the larger architectural and research community. For example, research findings are internally organized in a web-based document library since research findings need to be available to Perkins + Will's twenty-three different offices. This document library can be accessed through local Intranet and contains research documents, articles, white papers, project reports and guidelines, as seen in Figure 2. It is organized based on the topic of interest. Presentations and seminars are often organized to review and present research findings and disseminate results.

Some of the research results and studies are also shared with the broader architectural and research community through publications in external research publications, annual reports and the publishing of the Perkins+Will Research Journal, also shown in Figure 2.

Figure 2: Dissemination of research results.

The next two sections discuss specific case studies that illustrate relationships between research and architectural projects, discussing investigations of thermal comfort and outdoor design elements and façade energy studies.

2. THERMAL COMFORT AND OUTDOOR DESIGN ELEMENTS

2.1 THERMAL COMFORT

Thermal comfort is defined as "that condition of the mind in which satisfaction is expressed with the thermal environment" (ASHRAE 1993). Primary factors affecting thermal comfort are air temperature, humidity, air velocity, mean radiant temperature, clothing and metabolic rate (Atmaca et al. 2007). Mean radiant temperature is a significant factor, especially in areas with higher solar radiation.

Thermal comfort in exterior environments depends on design elements and climatic conditions. The human body reacts to combined effects of all climatic parameters. For instance, mean radiant temperature has the same effect as the air temperature with smaller wind velocities. Hoppe developed physiologically equivalent temperature (PET), which is defined as temperature at any place, outdoor or indoor, where heat balance of the human body is maintained with core and skin temperatures equal to those under the conditions being assessed (Hoppe 1999) . Table 1 presents several scenarios and accompanying PET values.

Scenarios	Ambient temperature Ta (°C)	Mean radiant temperature Tmrt (°C)	Air velocity	V (m/s)	Water vapor pressue VP (hPA)
Typical interior	21	21	0.1	12	21
Winter, sunny	-5	40	0.5	2	10
Winter, shade	-5	-5	5.0	2	-13
Summer, sunny	30	60	1.0	21	43
Summer, shade	30	30	1.0	21	29

Table 1: Selected PET values for several scenarios. Source: (Hoppe 1999)

For example, an occupant in a warm and sunny external environment with an ambient temperature of 30°C, mean radiant temperature of 60°C, relative humidity of 50% and air velocity 1.0 m/s would experience PET of 43°C. Blocking direct solar irradiation would result in a decrease of PET to 29°C. PET is an index that considers combined influences of climatic parameters; however, it is not an absolute measure of thermal comfort. It is independent of activity and clothing and needs to be adjusted according to these characteristics. For prediction of thermal comfort in exterior environments, several parameters must be taken into account, such as wind speed, air temperature, relative humidity, solar radiation, human activity, clothing level and physiological characteristics (Metje et al 2008).

The objective of this study was to investigate thermal comfort for a courtyard design located in Riyadh, Saudi Arabia, which is shown in Figure 3. The rationale behind the research was to investigate whether occupants would use this outdoor space if shading was not provided since these elements were subject to value-engineering. The research questions that were posed were:

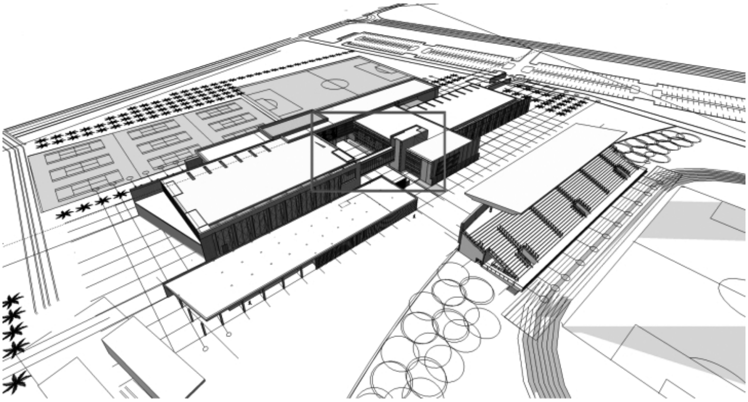


Figure 3: Courtyard design used to study design elements and thermal comfort.

- Would occupants be comfortable in an un-shaded courtyard?
- What would be the effects on thermal comfort and sensation during different months of the year?
- Would the courtyard be a usable outdoor space during milder conditions if shading is not provided?
- If shading is provided, what type of configuration and dimensions would be most appropriate for improving thermal comfort in this courtyard?

Effects of climatic and design conditions were investigated to assess perceived thermal comfort and physiological perception. Thermal Comfort Model, developed by the Center for the Built Environment (CBE) at the University of California at Berkeley, has been used to simulate the environmental effects on the occupants' comfort and thermal perception. CBE's Thermal Comfort Model (TCM) relies on complex relationships between environmental conditions and physiological response of the "thermal manikin", shown in Figure 4 (Huzienga et al. 2001). Thermal manikin represents an occupant within the considered environment. Physiological response is calculated based on the environmental conditions (temperature, solar radiation, wind speed) and relies on the principles of human thermal regulations. Human manikin can be divided into an arbitrary number of segments, but most applications use sixteen body segments, such as head, chest, arms and legs in order to differentiate responses. Moreover, thermal manikin can be modified to reflect characteristics of actual users, such as level of clothing, metabolic rate and physical characteristics. Physiological mechanisms are considered as well as different types of contact with the environment. Convection, conduction and radiation between the manikin and the environment are considered in the calculation of thermal comfort and thermal sensation indices. Spatial properties, such as dimensions, orientation, components (walls, windows) and description and placement of the occupant within the space are necessary for the computation. Non-uniform properties can be prescribed for individual elements where surfaces with higher exposures to sun may be assigned higher temperatures. Procedures for the study and results are outlined in subsequent sections.

2.2THERMAL COMFORT IN UN-SHADED COURTYARD

Riyadh is characterized by hot and arid climate, and IWEC weather data has been used to determine air temperature, relative humidity, wind speed and solar radiation inputs to the model. Six different scenarios were simulated for the un-shaded courtyard where base scenario was modeled for March. Summer conditions are most critical for this type of climate, where four months were selected (May, June, August and September) to the analyze comfort conditions within the outdoor space. One representative month for cold season was studied where January conditions were selected.

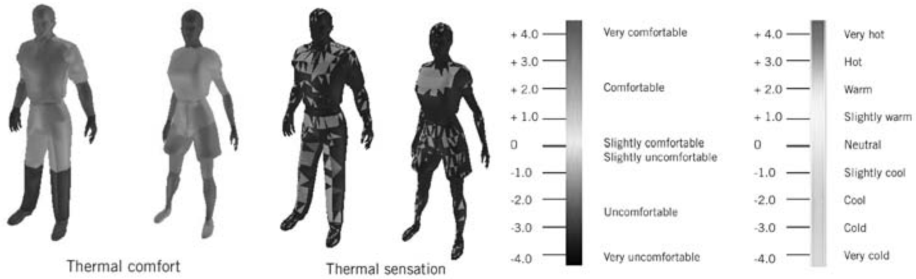


Figure 4: Thermal manikin types and measure indices for thermal comfort and sensation.

The scale for thermal comfort ranges from -4.0 to +4.0 where 0 represents neutral state, -4.0 is very uncomfortable and +4.0 is very comfortable. Thermal sensation is represented similarly where 0 is neutral, -4.0 represents very cold sensation and +4.0 represents very hot sensation, as seen in Figure 4.

Results indicate that without shading provision, occupants would feel uncomfortable and hot during summer months, which is expected in this type of climate. Thermal comfort would improve during winter months, however; results show that occupants would feel warm and uncomfortable even during these milder conditions. Results show that shading is necessary for all seasons and is crucial during hot months; otherwise the courtyard would be unusable. Therefore, subsequent analysis focused on the addition of shading elements and the effects of different configurations (varying orientation, position and dimensions) on thermal comfort.

2.3EFFECTS OF SHADING ELEMENTS ON THERMAL COMFORT

The months of August and September are representative of the hottest periods and previous results have indicated that conditions in the courtyard would be uncomfortable during the entire year if shading is not provided. August was chosen for analysis of shading effects on thermal comfort. Input parameters were identical to data presented in Table 2 and shading elements were added to the model. Configuration, dimensions, orientation and height of shading elements were varied to investigate effects on thermal comfort, as seen in Figure 5.

Overall, introduction of shading greatly improves thermal comfort and sensation as it is evident from the results. However, dimensions, height, percentage of shaded area, orientation and configuration

	Base model (March)	January	May	June	August	September
Inputs						
Air temperature Ta (°C)	25	20	34	40	43	37
Relative humidity RH (%)	60	70	30	25	25	40
Mean radiant temperature Tmrt (°C)	25	16	36	40	48	45
Wind speed (m/s)	2	2	2	2	2	2
Direct solar radiation (W/m2)	1000	1000	1000	1000	1000	1000
Diffuse solar radiation (W/m2)	250	250	250	250	250	250
Time (min)	180	180	180	180	180	180
Results						
Thermal comfort	-2.01	-1.58	-2.59	-2.66	-3.05	-3.05
Thermal sensation	2.45	2.08	3.17	3.22	3.43	3.44

Table 2: Inputs and results for thermal comfort in an un-shaded courtyard.

have different effects. For example, reduction in height of the shading elements greatly improves comfort (shading devices that are placed closer to the human body relative in height result in improved thermal comfort). The orientation and percentage of shaded area also influence thermal comfort where increased area and orientation of devices in both directions decrease radiant temperature of the surrounding surfaces and reduce direct solar radiation, thus resulting in improved thermal comfort. Thermal sensation is relatively high for all cases due to extreme temperatures; however, shading reduces direct solar gain and radiant surface temperature. Design strategies that would result in improved thermal comfort and thermal sensation include increased percentage of shaded area, lower height of shading elements in relation to human body, bi-directional orientation and uniformity in the design of shading surfaces. The study used simulations only and further investigation would be needed to analyze actual occupants' thermal comfort (such as through a post-occupancy evaluation).

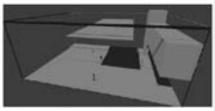
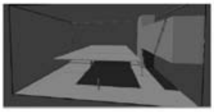
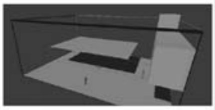
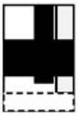
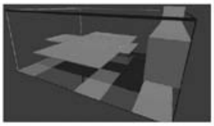
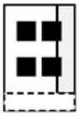
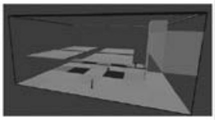
Properties	Percentage of area	Diagram	Model	Thermal comfort	Thermal sensation
Scenario 1 Width=24 m Length=14 m Height=10 m	46%			-1.69	2.36
Scenario 2 Width=24 m Length=14 m Height=5 m	46%			-0.82	1.97
Scenario 3 Width=15 m Length=20 m Height=5 m	41%			-1.63	2.24
Scenario 4 Component 1: Width=8 m Length=22 m Height=5 m Component 2: Width=24 m Length=14 m Height=5 m	64%			-0.87	1.73
Scenario 5 Component: Width=9 m Length=9 m Height=5 m	64%			-0.89	2.10

Figure 5: Shading configuration, properties and effects on thermal comfort and sensation.

3. FAÇADE STUDIES: ENERGY

3.1 OBJECTIVES

The objective of this study was to investigate building envelope design options and the effects on energy consumption for a commercial office building located in Riyadh, Saudi Arabia. Two completely different design schemes were proposed for this office building, as shown in Figure 6. The design schemes had different building form, orientation and façade treatment:

- Design scheme 1 used vertical fins for shading on single skin facade
- Design scheme 2 considered double skin wall

The study considered different building envelope scenarios for both design schemes focusing on the energy performance. The analysis considered a single zone office space and compared energy consumption for four different scenarios (for both design schemes 1 and 2). Assumed inputs for all scenarios are listed in Table 3.

Figure 6: a) Design scheme 1; b) Design scheme 2.

Design scheme 1: **model inputs for all scenarios (vertical fins)**	**Design scheme 2:** **model inputs for all scenarios (double skin wall)**
Space type: office Occupancy: 7 AM to 5 PM Occupancy load: 0.10 persons per m^2 Lighting load: 1.0 W/m^2 Equipment load: 5.0 W/m^2 Room dimensions: 3000mmX9000mmX4200mm Lighting control: dimming switch Facade window to wall ratio=80% Glass type: Reflective Properties of glass: • Visual transmittance Tv=0.26 • SHGC=0.30 • U-factor=2.498 W/m^2K	Space type: office Occupancy: 7 AM to 5 PM Occupancy load: 0.10 persons per m^2 Lighting load: 1.0 W/m^2 Equipment load: 5.0 W/m^2 Room dimensions 9000mmX10000mmX4200mm Lighting control: dimming switch Facade window to wall ratio=80% Glass type: Low-e (double IGU), clear (single glazing) Binds used in the double skin air cavity (white)

Table 3: Inputs for all scenarios.

3.2 DESIGN SCHEME 1: PERFORMANCE OF VERTICAL FINS

The analysis considered four scenarios for east-oriented office (as shown in Figure 6a), where the first scenario did not include any shading devices and the rest of the analyzed scenarios included vertical fins as shading elements with varying dimensions as indicated:

- SCENARIO 1: Base model (double air insulated glazing system, no shades)
- SCENARIO 2: Vertical fins (depth 375 mm, spacing 750 mm)
- SCENARIO 3: Vertical fins (depth 500 mm, spacing 750 mm)
- SCENARIO 4: Vertical fins (depth 500 mm, spacing 1000 mm).

Figure 7 shows monthly energy demand for all scenarios as well as cooling and lighting loads. It is evident that vertical fins would result in a reduction in the total energy consumption, mainly reducing cooling loads. Significant reductions in cooling loads would be achieved by providing vertical fins and the best-performing option was Scenario 3 consisting of 500 mm wide fins spaced 750 mm off center.

3.3 DESIGN SCHEME 2: PERFORMANCE OF DOUBLE SKIN WALL

This analysis investigated energy consumption for a typical office space using single skin façade and double skin facade for south-east and south-west orientations. Modeled typologies for double skin are shown in Figure 8. Scenario 1 considered single skin facade with double air insulated glazing

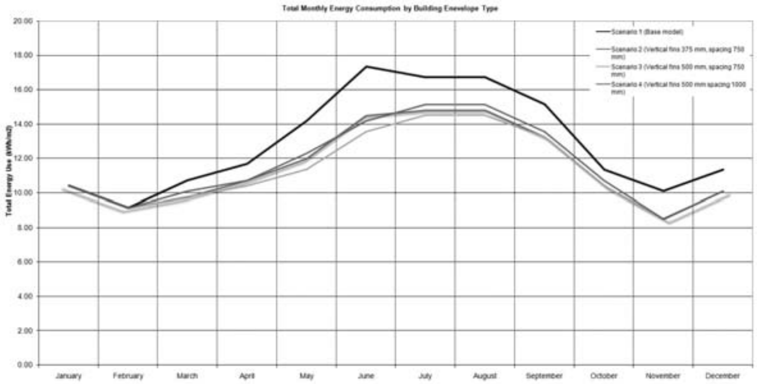
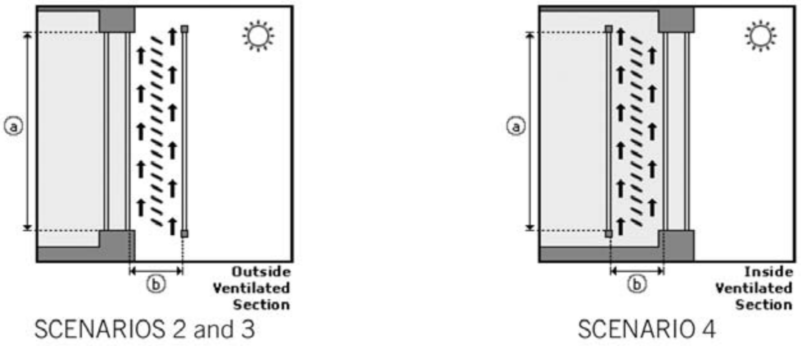


Figure 7: Total monthly energy consumption for design option 1 (all scenarios).

unit. Scenarios 2 and 3 considered exterior vent type double skin where double glazing is placed on the exterior and single glazing is placed on the interior portion of the facade. Horizontal blinds were considered as shading elements placed within the double skin air cavity. Two different air cavity dimensions were modeled (750 mm and 650 mm). Scenario 4 investigated interior vent type double skin where double glazing is placed on the exterior facade, single glazing on the interior side and with integrated horizontal blinds within the air cavity:

- SCENARIO 1: Base model (single skin façade, double low-e air insulated glazing unit)
- SCENARIO 2: Double skin, exterior vent type (mechanical cooling [air flow rate 50m3/h], air cavity 750 mm)
- SCENARIO 3: Double skin, exterior vent type (mechanical cooling [air flow rate 50m3/h], air cavity 600 mm)
- SCENARIO 4: Double skin, interior vent type (mechanical cooling [air flow rate 50m3/h], air cavity 750 mm)

Results for the south-east oriented office space (Figure 9) indicate that double skin facade (all types) would result in increased energy consumption compared to the base case scenario. The base case scenario has the smallest overall energy demand, especially during summer months. Scenarios 2 and 3 (exterior vent type) would decrease cooling loads compared to the base case scenario, however, lighting loads would be increased. This is due to the fact that natural light would have to penetrate two layers of the façade (with air cavity in between), thus reducing the illumination levels. Similar results have been found for south-west oriented facade. Overall energy demand would be slightly increased for this orientation compared to south-east orientation.



SCENARIOS 2 and 3

SCENARIO 4

Figure 8: Double skin façade typologies.

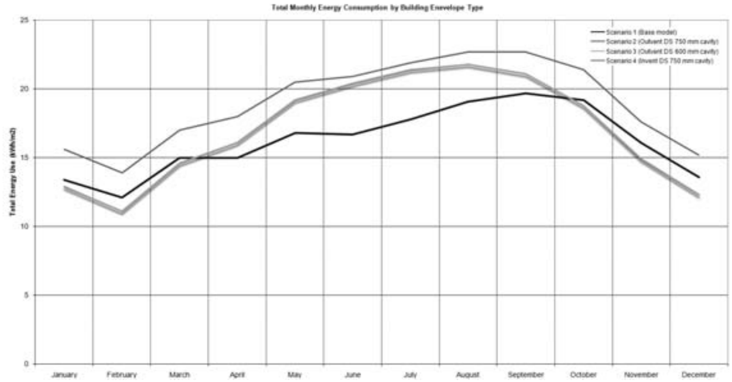


Figure 9: Total monthly energy consumption for design option 2 (all scenarios).

CONCLUSION

Buildings have traditionally relied on technological innovations as well as advancements in building science. Today, innovative materials, environmentally conscious design and new design processes for collaboration, simulations and virtual building are influencing design processes. This has caused convergence of design, technology and research within architectural practices where this synergistic relationship is transforming the traditional nature of architectural research and design. The emerging trend in architectural research is that practice-oriented research programs are gaining popularity, which are integral parts of leading architectural firms. This paper has reviewed objectives and research methods of such a program that focuses on building technology research. The benefit is that the conducted research informs architectural design (and conversely, architectural design informs research since it is driven by the requirements of architectural projects). Two examples have been discussed that illustrate how research and design process are integrated where research results inform the design decisions.

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