Beyond Blue and Red Arrows:
Optimizing Natural Ventilation in Large Buildings

by

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Wendy Meguro attended Massachusetts Institute of Technology from 2003-2005, prior to which she complete her Bachelor of Architecture at the University of Hawaii at Manoa. While at MIT, she was awarded the 2004 Skidmore, Owings, and Merrill Foundation Building Systems Technology Research Grant in addition to the MIT Rosenburg Traveling Fellowship to further her studies in naturally ventilated buildings. During her time at UH, she was awarded the Henry Adams Medal for most outstanding student, Alpha Rho Chi Medal for leadership, service, and professional merit, and others. Simultaneous to her coursework at MIT, she engaged in three interdisciplinary environmentally-driven design competitions: Pacific Palisades Mountain Hut, Urban Land Institute, and Cradle to Cradle. She had the privilege of working with Walters, Kimura, Motoda Landscape Architects, Kajioka Yamachi Architects, and Dinmore and Cisco Architects while in Hawaii.

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Abstract

Our growing understanding of technology and environment has expanded the complexities of producing large naturally ventilated buildings. While it may be argued that designing for natural ventilation is a straightforward, intuitive process, somewhere between the simple diagrams and signing off on the building, the designer must be able to verify that the design will be effective -- essentially that people will be comfortable, and that the system is robust. Today, professional experience is the only methodology to understand the broad considerations behind these new structures. Literature reviews and interviews with industry professional illustrate the lack of information available to the academic and practicing audiences describing the series of calculated decisions and challenges surrounding the design of large naturally ventilated buildings. Architecture professionals and students desiring to engage in these recent, innovative practices would therefore benefit from a resource describing the options available to evaluate a proposed design and optimize a completed building. The thesis examines the strategic decisions in evaluation and monitoring of three case study buildings (Morphosis' *San Francisco Federal building*, Fosters & Partners' *Swiss Re building*, and Behnisch & Behnisch's *Genzyme building*) and derives principles influencing future architecture practice.

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1. Introduction & Background

1.1 Summary

Our growing understanding of technology and environment has expanded the complexities of producing large naturally ventilated buildings. While it may be argued that designing for natural ventilation is a straightforward, intuitive process, to optimize the system and avoid liabilities, the designer must be able to verify that the design will be effective -- essentially that people will be comfortable, and that the system is robust. Today, professional experience is the only methodology to understand the broad considerations behind these new structures. Literature reviews and interviews with industry professional illustrate the lack of information available to the academic and practicing audiences describing the series of calculated decisions and challenges surrounding the design of large naturally ventilated buildings. Architecture professionals and students desiring to engage in these recent, innovative practices would therefore benefit from a resource describing the options available to evaluate a proposed design and optimize a completed building. The thesis examines the strategic decisions in evaluation and monitoring of three case study buildings and their implications on future practice.

The conclusions from the case studies and industry interviews provide insight into the future of large building natural ventilation design and green design in general. They suggest the need for [1] architects with an understanding of the overall process from project inception to post occupancy evaluation regarding coordination, time, funding, and people involved; [2] architects with knowledge of environmental simulation programs who can mediate between engineers' calculations and architects' agendas; [3] architects who can operate environmental simulation programs in-house for early design studies; [4] architects adept in researching and comparing the feasibility of environmentally-responsible systems; and [5] architects motivated to publish their experiences for the benefit of future projects.

1.2 Preface

There is a generally unexploited opportunity to employ natural (or hybrid natural and mechanical) ventilation in large (10+ story) buildings in temperate climates. This type of building is more desirable than its mechanically ventilated counterpart because of its potential to reduce its high air-conditioning energy demands, improve indoor air quality, and increase occupant comfort and control.

The advent of air conditioning permitted the construction of high-rise office buildings on a scale that would have been impossible before these mechanical means. The modern, sealed, glass-clad building typology resulted from a combination of the desire to push structural limitations, and to create large buildings as symbols of prestige and success. The facades of these buildings took on the same appearance, regardless of orientation, climate, or environmental conditions. The inoperable glass curtain walls trapped heat from the sun and electric lights, in addition to preventing fresh air from entering the interior. Instead of re-examining the architectural form to accommodate sun and wind conditions, designers applied massive heating and cooling systems to regulate temperature and air exchange. The U.S. Green Building Council's LEED guide states "operable windows are perhaps the single most desired feature building occupants request in the programming phase of a project," yet most large office buildings are sealed boxes, divorced from the outdoors.[i] Designers intended to create constant interior conditions, with little fluctuation in temperature or lighting; in other words, the occupants of those large sealed office buildings had little relation to the outside environment. This decision results in several disadvantages compared to spaces with operable windows and natural ventilation including [1] excessive energy use, [2] lack of user control and satisfaction, [3] inferior indoor air quality, [4] undesirable temperatures, and [5] disconnection from outside.

Today's architect has an awareness of the environment that makes it unacceptable to apply massive mechanical systems when a more clever energy-savvy solution is possible. The U.S. Department of Energy recognizes the environmental and international repercussions of the immense and wasteful energy use today. The DOE states, "Fossil fuels – coal, oil and natural gas -- currently provide more than 85% of all the energy consumed in the United States, nearly two-thirds of [the] electricity, and virtually all of [the] transportation fuels"[ii] and that reliance is expected to increase in the next two decades. The resulting carbon emissions and climate change alongside the desire to decrease dependence on foreign sources of fossil fuels gives motivation to re-examine energy use in the U.S. Energy use in buildings makes up 35% of all energy use in the United States.[iii] To manage energy use, a few strategies may be employed: [1] provide energy from renewable resources, [2] change consumer habits to use less energy, or [3] improve the efficiency of existing systems. This work addresses the latter two by designing the option for natural ventilation that is currently atypical for large buildings.

Cooling energy use is second only to lighting energy use in commercial buildings.[iv] In temperate climates, mild weather (at least in fall and spring) offers the opportunity for the building to breathe via natural ventilation. If the potential to significantly decrease energy usage in a large building is evident, why is it the exception instead of the standard?

While designers rely on rules of thumb and their own experience to design large naturally ventilated buildings, their educated guesses lack the quantitative analysis required to assure comfortable conditions. While it may be argued that designing for natural ventilation is a straightforward, intuitive process, somewhere between the simple diagrams and signing off on the building, the designer must be able to verify that the design will be effective -- essentially that people will be comfortable, and that the system is robust. This is where building simulation tools come into play, facilitating the designer by verifying performance assumptions. Yet discrepancies exist in how and when to use the tools and there are difficulties inherent in the process. For example, building simulation is often avoided because it is time consuming, requires expensive software, and necessitates a skilled, experienced engineer in order to achieve meaningful results. Despite these obstacles, a few leading architectural and engineering firms have employed simulation tools to design a new generation of ecologically-sensitive large buildings.

1.3 Definitions of comfort

One reason architects and engineers hesitate to design for natural ventilation is because they fear the building will not meet stringent standards regarding occupant comfort. The American Society of Heating, Refrigeration, and Air-conditioning Engineers sets forth specific standards, that describe the acceptable range of temperatures for certain spaces such as office buildings. The USGBC LEED guide defines thermal comfort as "a condition of mind experienced by building occupants expressing satisfaction with the thermal environment." But it is also important to recognize that people's comfort zones vary by location, age, and sex. For example, lightly clothed sedentary people report comfort in Britain at 58-70°F, in the US at 69-80°F, and in the tropics at 74-85°F.[v] Recent research moves beyond the unvarying temperature standards to examine how people physically and psychologically react to temperature swings in naturally ventilated buildings. Research by Brager and de Dear shows that "occupants of naturally ventilated buildings appear tolerant of – and, in fact, prefer – a wider range of temperatures than their counterparts within fully air-conditioned buildings."[vi] Most notably, the researchers observed that because the occupants in the naturally ventilated buildings did not anticipate a thermally neutral environment, they were more tolerant of temperature swings and made appropriate behavioral changes. In fact, "behavioral adaptations, such as changes in clothing insulation or indoor air speeds, could account for only half the observed variance in thermal preferences… this suggested the rest of the variance was attributable to psychological factors. Chief among these was a relaxation of thermal expectations, possibly because of a combination of high levels of perceived control and a greater diversity of thermal experiences in the building."[vii] As a result of the insights gained in this research, an 'adaptive model' of ASHRAE comfort standards has recently been adopted for naturally ventilated buildings. Understanding a wider range of acceptable comfort conditions opens the window of opportunity for more large naturally ventilated buildings by lessening the fear of liability that people will be uncomfortable. In comparison with the existing ASHRAE codes, the new adaptive standards will help promote the design of and make a stronger case for natural ventilation. When the comfort conditions are calculated or simulated, the adaptive standards will increase the appropriate amount of time natural ventilation can be used and increase the corresponding energy savings, making natural ventilation more appealing and sensible than under the current codes.

To demonstrate a different way of approaching the topic of meeting standards for natural ventilation, look at the example of political and climatic conditions in Switzerland. Swiss regulations not only recognize natural ventilation, but encourage its use. "Obtaining a permit to install air conditioning requires that designers show that it is really unavoidable and that there are no other low-energy-consuming alternatives that will produce comfortable ambient conditions inside the building."[viii] The political will and weather conditions in the US are obviously different from those in Switzerland, but it is relevant to recognize that standards play an important role in hindering or facilitating natural ventilation design.

1.4 Current literature resources for architects

In order to assess the natural ventilation potential of a proposed design, the architect may reference sources such as

- Natural Ventilation in Buildings by Francis Allard, 1998
- Chartered Institution of Building Services Engineers (CIBSE) AM10
- "Barriers to Natural Ventilation Design of Office Buildings", National Report: Great Britain, Building Research Establishment et. al, 1998
- Leadership in Energy and Environmental Design, US Green Building Council

While each of these resources is useful to the architect, notice that they provide little information on how to analyze the natural ventilation design's effectiveness. A short description of each of these resources will demonstrate how the architect may utilize them and where the gaps in information exist.

1.4.1 Natural Ventilation in Buildings: A Design Handbook

by Francis Allard, 1998

The handbook provides a relatively technical guide by condensing well-established diagrams and rules of thumb into one manual. The book is similar to most other resources in that it covers principles most useful in the initial stages of design. When designing a large building for natural ventilation, these simple diagrams may not adequately address the design challenges. Therefore a large building designer should refer to the section on obstacles that often arise in natural ventilation design.

The chapter entitled "Critical Barriers" divides the issues into three categories: [1] During building design - fire regulations, acoustic regulations, type of building use, controls, lack of suitable design tools; [2] During building operation – safety, noise, air pollution, shading, draught, user ignorance; [3] Other barriers: architectural impact, lack of suitable standards, increased risk for designers, fee structure for design. Although Allard notes the "lack of suitable design tools, lack of suitable standards, [and] increased risk for designers" the text lacks clear solutions to these difficulties. Allard states, "Natural ventilation has been an area where reliable tools have been conspicuously scarce," noting the variable wind conditions as the major stumbling block. "The tools that are available require a reasonable degree of user training and a good ability to interpret the results… Thus, most designers will not feel too comfortable using them and may even feel distrustful and confused by the often contradictory recommendations for different wind patterns." Allard concludes with the statement, "This difficulty still has to be overcome with the development of new software packages," offering no practical advice to architects on how to navigate the process of using design tools. Although a few simulation tools are briefly named, there is no explanation of who should use the tools, when they are appropriate, and what the expected outcomes mean for design.

The purposes for evaluating the airflow conditions in a proposed building are adequately described by Allard in the chapter on prediction methods:

> *Designers wish to know the airflow rate through large openings to size building windows appropriately, while engineers are interested in the distribution of the air velocity in a zone to size ventilation inlets and outlets. Comfort experts wish to know the air velocity values in a zone to calculate heat convection from or to the human body, while air quality experts are interested in the flow rate, the dispersion of contaminants and the ventilation efficiency.*

The four types of prediction methods Allard suggests are empirical models, network models, zonal models, and computational fluid dynamics (CFD) models.

1. The empirical model assumes the building is a single zone and determines the bulk air flow rate in the earliest stages of design. This method of analysis does not provide meaningful results for the architect designing a large naturally ventilated building since the building is not usually one large zone.
2. The second method, the network model, represents the interior and exterior conditions as nodes with different pressure values. This method of analysis is un-intuitive and too technically intense to be a desirable for the architect.
3. The zonal model is described as the most applicable for use by architects because of its accuracy and simplicity. The zonal modeling tools currently on the market are geared toward engineers, not architects, and are therefore not a common tool in design. Because Allard's book is from 1998, I assume the current (2005) example of the zonal model is the EnergyPlus simulation used in the San Francisco Federal building. In this model, one floor was modeled as one zone and the chimneys/stacks were modeled as a second zone. A multi-zone modeling tool geared toward architects is under development at Massachusetts Institute of Technology and is discussed in this thesis under the section "The future of simulation tools."
4. The fourth evaluation method described by Allard is the computational fluid dynamics (CFD) model. From my own experience using CFD simulations in an educational setting, the CFD models' long calculation time and required expertise make them inaccessible to the architect desiring to quickly test a design.

The description and evaluation of Allard's proposed prediction methods demonstrate that they are inaccessible to the architect. Allard does not go further to suggest the next steps in modeling. This thesis will address the need for either a strong collaboration between architect and engineer who can run these simulation programs, or development of modeling tools for architects. The case studies show how modeling played a crucial role in verifying the design's effectiveness, and how it should be applied to future projects.

Allard's book also contains a section entitled "Natural and Hybrid Ventilation systems in contemporary non-residential buildings." This is useful because it thoroughly describes the strategies employed by each building, but it does not explain how the designers arrived at those strategies and what was required to overcome the barriers discussed in earlier chapters. Interestingly, there is one case study of an office building (Meletitiki Ltd. in Greece by A.N. Tombazis Assoc.) that discusses how the natural ventilation strategy was executed. It appears that the building's natural ventilation was designed from rules of thumb, and only underwent simulation of night cooling after the building construction was complete as a means to address unanticipated cooling needs. This is counter-intuitive to the usual method of engaging in simulation before, not after, the building construction is complete. This reinforces the notion that a reference on the use of building simulation tools in exemplary projects would help designers decide how to apply them in future projects.

1.4.2 "Natural Ventilation in non-domestic buildings"

by Chartered Institution of Building Services Engineers

The next resource an architect might refer to when designing a large naturally ventilated building is Chartered Institution of Building Services Engineers (CIBSE) Applications Manual (AM10) 1997 entitled "Natural Ventilation in Non-domestic Buildings." Produced by CIBSE and the Building Research Establishment, it "provides guidance on natural ventilation that is strategically important to architects, building services engineers, clients, and their advisors." It is a very thorough reference and includes prescriptive guidance on natural ventilation, covering physical components and assemblies, and case studies. This guide prescribes an eight-step process for natural ventilation:

1. *Develop design requirements*
2. *Plan airflow paths*
3. *Identify building uses and features that might require special attention*
4. *Determine ventilation requirements*
5. *Estimate external driving pressures*
6. *Select types of ventilation devices*
7. *Size ventilation devices*
8. *Analyze design*

If architects are interested in testing a natural ventilation design, they should refer to the CIBSE guide section on "Description of Design Tools." Discouragingly, they would then find lengthy, unapproachable hand-calculation methods more geared toward engineers than architects. The description of computer and physical modeling methods is thorough and easily understood, but does not put them into a context of architecture or engineering firms. In other words, the time, people, and common difficulties that a designer would want to know before using these methods are not addressed. The case study matrix detailing 23 buildings efficiently summarizes the approaches of each, but does not have a category for the testing methods used. The CIBSE case studies dedicate a paragraph or two to the intent of the computer analysis, but do not detail the complexity, coordination, time, and cost expectations that would be useful to a project manager or architect.

1.4.3 “Barriers to Natural Ventilation Design of Office Buildings”

National Report: Great Britain, Building Research Establishment, Willan Building Services, et.al. 1998.

The study, based on interviews and questionnaires, gauged the perceived barriers to natural ventilation in the UK as part of a larger European study sponsored by NatVent[1] and the European Commission. The study becomes a springboard for this thesis with its reported barriers and future needs regarding design tools. Conclusions of the study state that

> *“there was a significant lack of knowledge and experience on special designed natural ventilation... It was clear that guide sources to natural ventilation with working examples was required with more accurate calculations. Desirable new design tools included demonstrable performance of natural ventilation, well documented and monitored case studies, updated CIBSE [ASHRAE equivalent] guides and more simple and advanced computer program design tools.”*

1.4.4 LEED: “Indoor Environmental Quality”

The US Green Building Council’s reference guide Leadership in Energy and Environmental Design (LEED) informs designers of the breadth of environmental considerations and has changed the way designers approach architecture projects. The LEED rating system should be applauded for bringing green buildings to a visible position in the forefront design today. The LEED rating system is recognized for being forward thinking because it guides designers to think beyond simply meeting codes and apply logical environmental strategies. The first of its kind in the US, (the UK equivalent is BREEAM) the system does have room for improvement. There is a danger that designers will focus on the checklist of credits instead of a holistic environmentally-sound design strategy. The LEED system is an inadequate resource to designers of large naturally ventilated buildings because it does not address natural ventilation strategies, testing methods or operable windows in depth.

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[1] NatVent™ 'Overcoming Technical Barriers to Low Energy Natural Ventilation in Office Type Buildings in Moderate and Cold Climates' 1999.

Under LEED's "Indoor Environmental Quality" portion there are sections on "Increase Ventilation Effectiveness" and "Controllability of Systems" applicable to natural ventilation design.

"Increase Ventilation Effectiveness" recognizes that "natural ventilation provides a strong connection to the outdoors and has very low operation and maintenance costs." The requirement for this section is as follows:

> *"For naturally ventilated spaces, provide airflow simulation results including locations of inlets, outlets, and flow patterns. Provide a narrative with graphics describing the sequence of operations of the ventilation system and demonstrate that distribution and flow patterns in all naturally ventilated spaces involve at least 90% of the room or zone area in the direction of air flow for at least 95% of hours of occupancy."*

In describing the applicable technologies, the LEED reference is somewhat vague, avoiding detail:

> *"Natural ventilation schemes must rely on openings in the building envelope to develop beneficial air flow. Incorporate operable windows into architectural design strategies to realize natural ventilation, cross ventilation, and stack effects. These schemes require study of inlet areas and locations as well as airflows.*
> *Elements to incorporate in the building ventilation design scheme include windows, doors, non-powered ventilators, and building infiltration. A computer model can be developed to mimic ventilation processes and determine the best location for these elements."*

Note that the computer model is mentioned in reference to locating openings. There are many other capabilities and applications of computer models that could be outlined here or mentioned in the "resources" section.

The LEED section on **"Controllability of Systems"** intends to "provide a high level of individual occupant control of thermal, ventilation, and lighting systems to support optimum health, productivity, and comfort conditions." The credit involves providing drawings and calculations showing fulfillment of the following requirements:

1. *"Provide a minimum of one operable window and one lighting control zone per 200 sq. ft. for all occupied areas within 15 feet of the perimeter wall.*

2. *Provide controls for each individual for airflow, temperature, and lighting for 50% of the non-perimeter, regularly occupied areas."*

1.4.4 Current academic endeavors

Two other academic research endeavors address similar topics. First, is an Massachusetts Institute of Technology PhD thesis by Singha Intrachooto entitled *Technological innovation in architecture : effective practices for energy efficient implementation.* Intrachooto's thesis uses case studies to examine processes by which design teams achieved energy efficient innovation. Intrachooto's thesis has multiple layers of interesting information and carefully detailed case studies that are useful to architects, mainly around the subject of the dynamics of the design team.

Second is a Norwegian University of Science and Technology 2003 Doktor Ingenior thesis by Tommy Kleiven entitled *Natural Ventilation in Buildings: Architectural concepts, consequences and possibilities.* Kleiven concentrates on how natural ventilation influences building form. Kleiven's thesis is useful to the architect looking for precedents in "modern" natural ventilation aesthetics – that is the resulting forms of the overall building massing, façade, roof, and interior spaces. The many buildings and photographs are more aesthetically inspirational than typical two-dimensional, rule-of-thumb natural ventilation diagrams. The thesis is also useful to architects because it includes case studies of a high-rise, medium-rise, and low-rise building, facilitating a relevant comparison to their current project.

My own thesis compliments these two previous works by going into detail about the verification of the natural ventilation ideas during design and questioning how the actual performance compares to the predictions. In other words, the topic included here that is not fully explained in Intrachooto or Kleiven's theses is how the designers used different evaluation methods to confirm the effectiveness of the natural ventilation scheme.

2. Industry Interviews

Interviews with industry professionals were supported by the 2004 Skidmore, Owings, and Merrill Foundation Building Systems Technology Research Grant and also the MIT Rosenburg Traveling Fellowship. This chapter consists of the report submitted to SOM in fulfillment of the grant. The interviews provide a better understanding of the state of progressive practices in the architecture industry today and lay the foundation for the case studies. The overview, description of the proposed study, and the methodology are explained first. The interview results are categorized under two subjects: building simulation tools and post-occupancy evaluation.

The section on building simulation tools covers

- Computer modeling during schematic design
- Computer modeling during design development
- Commentary on the usefulness of computer modeling
- Other methods of modeling

The section on post-occupancy evaluation

- Is post-occupancy evaluation necessary?
- Common reasons for sub-optimal building performance
- Opportunities and limitations of existing monitoring programs
- Ideas on facilitating post-occupancy evaluations

The summary, implications, and ideas for future work provided a springboard to the case study and analysis work completed after the interviews.

2.1 Overview

The following research endeavor summarizes the findings from a series of interviews were conducted with architects and engineers at leading firms in the UK during the summer of 2004 regarding two issues relevant to designing multi-story buildings employing passive ventilation strategies. The first topic attempts to optimize the dialogue between architects and engineers by defining the constraints and opportunities of building ventilation simulation methods. The second topic addresses the need for post-occupancy evaluation methods to be employed in passively-ventilated buildings while examining the barriers and gathering suggestions on how this process might be facilitated. The scope of this project involves examining the design process itself, referencing specific buildings for the purpose of illustrating broader statements. The buildings discussed range from three to 40 stories high, and utilize a building management system to operate the passive ventilation systems during appropriate times of the year. This research is formatted not only to report how the cutting edge firms are operating today, but also how they evaluate the relevancy of their tools in terms of accuracy and preference in methodology. Although the chapter discusses the design process, the scope does not include re-stating initial parameters for natural ventilation (including appropriate temperatures, humidity, wind speed, and building function), but instead focuses on the methods available to confidently test and compare designs for passive ventilation.

2.2 Proposed Study

Passive ventilation addresses several pertinent issues including the opportunity to decrease energy used on cooling loads, improve indoor air quality, and increase occupancy comfort. The design of large-scale passive ventilation requires careful coordination between the architect and engineer as well as the quantitative confirmation of comfort conditions through the use of building simulation tools. At the present, there is a suboptimal architect/engineer relationship in which the architect lacks simple tools for initial design analysis and usually lacks understanding of the constraints of the engineer's analysis process. A productive dialogue between architect and engineer is necessary to facilitate the exchange of ideas and allow for iterations to optimize design. Few firms have achieved this ideal collaboration on a consistent basis, and my research focuses on dissecting how those firms use simulation tools and building monitoring to inform the design process for passive ventilation. The first topic discussed examines the role of building simulation tools in leading architecture and engineering firms relative to their purpose and influence in various stages of the design process.

The second component of the research addresses the need for post-occupancy evaluation of passively ventilated buildings to determine if they are performing as expected and to apply those findings to future projects. Post-occupancy evaluations are often difficult to arrange or lack funding. The interviews offer the opportunity to evaluate current practice and reflect upon potential improvements to the data collection methods and building performance evaluation techniques.

2.3 Methodology

The information gathered is a series of opinions and stories based on experiences in designing and building passively-ventilated buildings. The interviews generally consisted of an hour to two hours of discussion initiated by questions framing the previously stated issues. All interviews were arranged by email and phone through the initiative of the researcher and the graciousness of the professionals. To facilitate documentation, the discussions were recorded on tape and later transcribed. Those thoughts were then compared, identifying conflicting opinions, patterns in response, and suggestions for improvement.

The questions stated are intentionally broad. To avoid skewing the interview with the researcher's own hypotheses or biases, the questions are structured to allow the professionals to respond based on those issues most prevalent in their experiences. The initial comments or stories provided a basis for more specific questions. Upon commencement of the research, my objective was to record how leading firms engaged in the process of passive ventilation design and format it into a resource that less experienced designers could reference. After engaging in the discussions, it became clear that opinions and methods for passive ventilation design differed within the profession and therefore could not be assembled into a singular guide. As a result, this research is formatted not only to report how the cutting-edge firms are operating today, but also how they evaluate the relevancy of their tools in terms of accuracy and preference in methodology. This information should facilitate the dialogue between architects and engineers because it basically outlines what to expect from simulation and follow-up when engaging in a multi-story passive ventilation system. This information is also of interest to firms proficient in passive ventilation design as a basis for comparison and instigation of possible improvements.

The people and firms that graciously participated in this survey are as follows. I would also like to take this opportunity to thank them for their generosity in giving their time, expertise, and reference materials to aid the research.

- Feilden Clegg Architects
  - Bill Gething, Partner and RIBA Sustainability Advisor
- Foster & Partners
  - Rob Harrison, Project Architect on Swiss Re
- Hopkins Architects
  - Gary Clark, Architect
- Max Fordham LLP
  - Bart Stevens, Group Leader
  - Philip Armitage, Partner, Cambridge Office
  - Greg Smith, Mechanical Engineer
  - Lorna Max, Mechanical Engineer
  - Meredith Davey, Mechanical Engineer
- Ove Arup & Partners
  - David Richards, Associate Director of Structural and Building Services
  - Mikkel Kragh, Façade Engineering
- Short & Associates
  - Quinton Pop, Architect
- University of Cambridge, BP Institute
  - Shaun Fitzgerald, Researcher
- Usable Buildings
  - Bill Bordass, Co-Founder
  - Adrian Leaman, Co-Founder

2.4 Interview Results

2.4.1 Question 1:
What are the objectives of using building simulation tools during various stages of the design process?

The responses to this question are categorized into four areas:

I. Computer modeling in schematic design
II. Computer modeling in design development
III. Commentary on the usefulness of computer modeling
IV. other types of modeling (not computer) used and their value

I. Computer Modeling in Schematic Design

When designing a passively-ventilated building, most of the interviewed architects and engineers identified a few critical points in schematic design. The first is that in order to achieve an energy-efficient, passive design, the architect and engineer must collaborate very early on in the project. Architects need rules of thumb from the engineers, to inform the general massing, orientation, and openings in the building based on environmental cues. Informed decisions are made when the engineers then run quick calculations via spreadsheets or uncomplicated software to compare one design to the next. From the engineer's point of view, the method of testing during initial design stages must be simple and fast ("quick and dirty") so that designs may be quickly altered and tested again. Detailed simulations are undesirable at this stage because of the long turn-around time and expense involved when it is probable that the building design may change significantly.

> *"I know modeling, and I know when it should come in, but the real problem is budget. It's very costly in terms of man-hours. You don't want to do it unless you really have to. If the building changes then the models have to be done again. Engineers don't want to do complex modeling too early because they know the building will change. So it's a chicken and egg type of situation, where [architects]are always trying to say 'You need to tell us the defining parameters for us to be able to design.' Sometimes the [engineers] give approximate rule of thumbs, which will set up the design, then we'll test it." – Gary Clark, Hopkins Architects*

> *"The architect needs a very good feel for the rules of thumb to do the rough analysis for ventilation and daylighting. And [Max Fordham engineers] were very good about providing estimates (i.e. you need about*

> *50% wall area for ventilation) but then they were able to back that up with hard calculations soon after the meeting to see whether they were right or wrong... At that time they use many simple spreadsheets, changing one variable at a time to see what happens." - Bill Gething, Feilden Clegg*

> *"An in-house software is used for energy and thermal analysis (and natural ventilation.". –David Richards, Associate Director of Structural and Building Services, Ove Arup*

II. Computer Modeling in Design Development

In the Design Development stage, once the building is more resolved, full thermal and/or airflow simulations are engaged at least twice, indicated by architect Gary Clark of Hopkins Architects. These simulations are methods to test assumptions about the comfort conditions. The feedback from these models should locate areas that need to be further addressed (areas that are showing undesirable results). This is the stage where a knowledgeable, experienced engineer has the opportunity to influence the design because as he/she runs the simulation, he/she may suggest changes to optimize the form or systems. Once changes have been implemented the models should be run once more to verify the building's performance.

III. Commentary on the Usefulness of Computer Modeling

When assessing the value of thermal and airflow computer simulation techniques for passive ventilation design, three answers emerged. The first addresses the [in]accuracy of the programs; some opinions revealed thermal simulations are useful in comparing one design scheme to the next, but not necessarily accurate in predicting exact temperatures. The opinion that the computer simulation could be inaccurate was based on the professional's experience in which temperature readings in the computer simulations were different from temperature readings taken in the actual building. Secondly, these simulations are useful in locating areas that need to be further addressed (i.e. where the design should be changed). Third, the models should be run once more to confirm the building's performance after changes have been implemented.

In addition, the building simulation results should be presented as a range of performance possibilities based on how the building is operated (influenced by the user's actions). In other words, while simulation results present the optimal operating condition, the energy and comfort projections should include the realistic possibility that users will mismanage the building. For example, interior partitions or manual override of automated openings might compromise the building's performance.

> *"Using simulation as a presentation tool, it's a nice idea to say 'that's what the building is capable of' and show a range of if the client operates it badly." – Gary Clark, Hopkins Architects*
>
> The following is an excerpt from a conversation with engineer Bart Stevens at Max Fordham:
>
> **BS:** *"This is an analysis program we've got in house that's a bit better than a spread sheet. It's about half way between a spreadsheet and TAS. ... It gives you a really good feeling overall if the building is going to work, or if this design better than that design." – Bart Stevens, Max Fordham*
> **WM**: So in this case the in-house software is used as a design tool?
> **BS:** *Yes, and I think it's much more useful for naturally ventilated buildings because you've got to run so many of them. We ran it 32 times on the BRE building..." – Bart Stevens, Max Fordham*

IV. Non-Computer Modeling Techniques and Their Usefulness

The other types of modeling, such as wind tunnel tests, physical mock-ups, or water bath models, can also be useful in simulating the airflow in a building. The various techniques discussed during the interviews will be mentioned briefly here, in the context of their applicability in the design process. The details of how the techniques work will not be described in depth here because other texts may be easily referenced for the subject.

Wind tunnel tests are useful in the ventilation design process to help identify areas to explore further and focus in on with Computational Fluid Dynamics. The wind tunnels are used primarily for urban-scale analysis, as opposed to modeling the interior of a building. One reason for this is because the lack of ability to simulate thermal conditions in a wind tunnel model. The wind tunnel is more useful for structural analysis, and less useful for ventilation design.

Physical mock-ups of sections of the building are used to understand assemblies, test for water and air infiltration, and analyze acoustics. The interviews did not describe exactly how physical mock-ups are used in ventilation design, so some possible applications are speculated here. The façade might be tested for air tightness, pressure differential across a façade may be drive air leakage a buoyancy-driven ventilation system. Façade leakage can also be a problem in a wind-driven ventilation situation as well. In addition, the actuators or sensors for operating windows and their assemblies to the frame could be tested in the physical mock-up.

A handful of research communities are working with water bath models to simulate single-volume building spaces. Based on the interviews, it appears that water bath (saline solution) models are being used only at research institutions such as Imperial College, University of California San Diego, and Cambridge University (BP Institute). Some of Alan Short's professional work in architecture has undertaken collaborations with Cambridge University for water bath modeling.

> *"Parallel to the computer environmental modeling there is a similar track of physical modeling of parts of the building, from typical bay details to large-scale details, for wind infiltration or acoustic tests." – Gary Clark, Hopkins Architects*

2.4.2 Question 2:
Is post-occupancy evaluation necessary? If so, how might it be facilitated?

The responses to this question are categorized into four areas:

V. Is post-occupancy evaluation necessary?
VI. Common reasons for sub-optimal building performance
VII. Opportunities and limitations of existing monitoring programs
VIII. Ideas on facilitating post-occupancy evaluations

V. Is post-occupancy evaluation necessary?

The interviews revealed a consensus among both architecture and engineering firms that post-occupancy evaluation is especially relevant and necessary for passively-ventilated buildings. The major barrier to post-occupancy evaluation is the difficulty in allocation of responsibility and securing financial support. The building facilities manager, the building controls company, the engineer, and the architect could all potentially oversee the monitoring process. It is critical that those responsibilities are clearly defined and funding is included in the building contract.

> *"There are multiple reasons for monitoring. The first is the commissioning of the building, second is a PR tool, and third is to learn for future... But also, [monitoring] does show various things that even computer simulations can't." Greg Smith, Mechanical Engineer, Max Fordham*

> *"Personally, I'm very keen on monitoring because you essentially use it as the commissioning process." – Greg Smith, Mechanical Engineer, Max Fordham*

> *"If you don't know whether the things you're specifying work in practice, it's hopeless." - Bill Gething, Feilden Clegg Architects, RIBA Sustainability Advisor*

> *"The clients and facilities managers are getting more interested in [post occupancy evaluation]. Once clients know the cost [of a poorly-operating building] in terms of management, time, lost productivity, and life-cycle of their building components, they are interested in post occupancy research." – Gary Clark, Hopkins Architects*

VI. Common reasons for sub-optimal building performance

In the discussions, the three most common reasons for sub-optimal building performance were 1) occupants' unawareness of building operation requirements; 2) physical breakdown of building components; 3) air infiltration because of sub-standard quality of materials or construction.

First, if the occupant does not understand how the building should be operated in different weather conditions, he/she might be counter-productive to the passive ventilation scheme. For example, the occupant might construct interior partitions and unknowingly blocking the airflow. The most obvious solution to this issue is to create a way for the designers to express their intentions to the users, either through written methods or through personnel. Because most building occupants are not inclined to read the Operations and Maintenance manual, there is a need for a different method of communication between the building designers and end users. Some strategies discussed include daily briefings via email or indicator lights to instruct window operation. Even if the facilities manager is familiar with the ventilation strategy and its requirements, periodic assessment of its performance is not usually included in his/her responsibilities. In addition, as staff is replaced, knowledge of the building operation is not usually communicated. Therefore the building design must be both robust (anticipating abuse) and intuitive (should not require specialized knowledge from the user).

Second, in passively-ventilated buildings, the sometimes unprecedented combinations of building assemblies or the complexity of the building management systems (BMS) result in physical breakdown of components. In some cases, the source of the problem is not readily apparent and the designers or facilities managers are only notified when users complain of uncomfortable indoor conditions. This highlights the opportunity for facilities managers to identify and repair problems faster by reviewing and responding to data (such as temperature) collected by the BMS.

Third, air infiltration was identified as a primary reason for poor building energy performance. Usually infiltration was a result of sub-standard material quality or careless construction. The assembly components of windows, sensors, actuators, and BMS, are often produced by separate manufacturers and require builders to have a certain level of expertise and experience to construct and coordinate properly.

> *"We told the client he must never put up a partition here [blocking cross-ventilation]. And, presto, the client put up a partition here and the natural ventilation didn't work. You should design buildings to be forgiving, so the client can mess them up, and they'll still work." – – Greg Smith, Mechanical Engineer, Max Fordham*

> *"There are all sorts of reasons why buildings might not work; either components fail and no one knows how to repair them, or the design doesn't work, or occupants don't understand how the thing's supposed to operate it so they might do something like jam a window open that shouldn't be." - Bill Gething, Feilden Clegg Architects, RIBA Sustainability Advisor*

> *"One thing that monitoring can show, which is quite interesting, is it can reveal physical breakdowns that would normally go unnoticed. [After noticing inconsistent BMS data] ... we found a brick stuck in the damper which wasn't allowing it to close. So I think monitoring is an invaluable tool." Greg Smith, Mechanical Engineer, Max Fordham*

> *"Another problem is when you're commissioning, and you're going to commission during the middle of summer or winter you have to simulate the other seasons. So when you're commissioning you put in all kinds of silly fiddles [i.e. changing set points], to check if it's working. But if you forget to take those fiddles out, which often is what happens, you find the building working ineffectively. And that's where a lot of the problems come from. It's human error." Greg Smith, Mechanical Engineer, Max Fordham*

> *"In terms of post occupancy studies that have been done, wind infiltration is one of the top items that [determines] the energy difference between predicted and actual. [In response] the new regulations in the UK, especially BREEAM, ask for a pressure test of the building. - Gary Clark, Hopkins Architects*

VII. Opportunities and limitations of existing monitoring programs

Experts in the field of post-occupancy evaluation such as Bill Bordass and Adrian Leaman have documented and evaluated hundreds of buildings through the Usable Buildings Trust. The post occupancy evaluation work done by Adrian Leaman bridges the gap between engineers and social scientists by linking quantitative information on topics like indoor air quality to occupant comfort and productivity. He argues that good building management is just as important as good design. In conversation with them and others, two opportunities to improve existing monitoring frameworks became evident.

First, there was a clear need to assign, in the contract, monitoring responsibility to a specific person or group. In theory, this should not require excessive time or financial resources because the data is already being collected by the BMS, and simply requires a knowledgeable reviewer trained to recognize irregularities.

Second, one building's data is most useful when compared to a database of similar buildings' performances as well as with energy-use targets. While some buildings are monitored and recorded as part of a research grant or owner-funded endeavor, this sort of evaluation is not the industry standard. By making the compilation and comparison of data a standard part of the commissioning process, design firms would benefit by the opportunity to compare their projected goals to the actual building performance; in addition, occupants would benefit from the opportunity to fine-tune the BMS for optimal comfort and energy-savings. Comparing one building's performance to energy-use targets (present and future) provides feedback to design firms, which in turn motivates and informs future buildings.

> *"If you've got a BMS, you get this data practically for free. The problem is accessing all that data because you've got such a mass of it." Greg Smith, Mechanical Engineer, Max Fordham*

> *"The post occupancy evaluations are only useful when you can compare the results with other buildings. Then you need a standardized procedure such as Bill Bordass' system with a database of hundreds of buildings in the UK that's linked to a satisfaction survey." - Gary Clark, Hopkins Architects*

VIII. Ideas on facilitating post-occupancy evaluations

When asked to speculate on how one might facilitate post-occupancy evaluations, the subjects' responses combined clever creativity with practical industry knowledge. The ideas can be distilled into two prime approaches: 1) increasing public demand and 2) changing the designer's fee structure. By increasing public awareness of the conditions impacting the health and energy-use in a building, demand for "sustainable" buildings and services like post-occupancy evaluations will increase. Secondly, there is a need to rethink the typical relationship where engineering fees are proportional to mechanical-equipment size. Alternatively, one might structure the engineers' fees on a performance basis in such a way that they are rewarded for energy savings.

> *"The key is to try and get the public on your side. The public will say, 'What green features has this building got?' ... and will hopefully choose the building with the higher rating." Greg Smith, Mechanical Engineer, Max Fordham*

> *"After one year, the design firm should review data, assess performance, affirm that things like the mechanical actuators and set points are working properly, and review algorithms (i.e. is the night cooling enough?). The facilities manager should have the maintenance of the BMS included in his duties and salary. A certain amount of the capital cost should be dedicated to the review done after one year of operation." –Shaun Fitzgerald, BP Institute*

> *"What you need at an early stage are engineers who are interested in reducing building services. So they need to be employed, not on the basis of the amount of services they extort, but employed on the basis of the total cost of the building." - Bill Gething, Feilden Clegg*

> *"It would be great to come to a point where the engineers get paid more for designing less ... you don't want the engineers' fees to be related to the construction cost of their mechanical kit" – Gary Clark, Hopkins Architects*

> *"In Europe, a directive was passed last year, for energy labeling. It makes energy efficiency a purchasing criteria. All public buildings will get grades ... It should affect the way the public perceives these buildings (and presumably a good rating would increase their market value)." -- Shaun Fitzgerald, BP Institute*

> *"The only way the client would pay for post occupancy evaluation is to add it to the contract, so it becomes another line item on the construction cost plan. Research bodies might want to do it themselves. At Jubilee Campus, the students have done their own post occupancy evaluation." -- Gary Clark, Hopkins Architects*
>
> *"Tie feedback and post occupancy evaluation into project delivery and follow-through. Include project goals that can be measured after building." –Bill Bordass,* usablebuildings

2.5 Interview Summary

From the interviews, one may infer a series of statements about the architecture and engineering practice today with regards to simulating and monitoring a naturally ventilated building:

a. The architects did no in-house airflow simulation. Early dialogue with engineers to determine initial moves such as orientation, massing, and form of the building is critical if natural ventilation is desired.

b. In the early stages of design, engineers ran many "quick and dirty" calculations to test the impact of different variables. In house software, less complex than a full simulation, was most often used for this application.

c. Full airflow simulations were only used if the building design was innovative or bespoke. The simulations were used for verification of assumptions and identification of areas that needed modification.

d. Firms confirmed that post-occupancy evaluation is beneficial to building occupants and design firms. Buildings may not be operating optimally because 1) occupants lack of understanding of building operation; 2) building components physically breakdown; or 3) sub-standard quality of materials or construction leads to air infiltration.

e. Monitoring responsibilities need to be clearly defined. Results are most relevant when compared to other buildings and energy-use goals.

f. Post occupancy evaluations might be facilitated by encouraging public demand and changing designer's fee structure.

2.5.1 Implications for architecture practice

These findings illuminate several principles and opportunities regarding natural ventilation design. First, these successful building examples demonstrate the necessity for an open dialogue and debate between the architect and engineer from a very early point in the design process. This is critical because while the architect may rely on "rules of thumb" to guide ventilation principles, the engineer has the analytical ability to run numerical calculations, useful in comparing one design scheme to another. In addition, it is likely that an experienced engineer's intuition will allow him/her to suggest modifications to the building design. Even during schematic design, without the engineer's input, the architect can only speculate on airflow predictions.

> *"We try to work with architects right at the beginning of a project, maybe when there's nothing designed on paper at all."- Bart Stevens, Max Fordham*
>
> *"If [the engineers are] involved right at the start, I think it can make a huge difference. Before the building's got any form, we can look at orientation, the site, landscape, there's a huge impact we can have." Lorna Max , Max Fordham*

2.5.2 Future Ideas

The architect lacks the ability to quickly conduct quantitative calculations to compare design schemes. This highlights an opportunity for the development of a tool geared toward architects facilitating the evaluation of ventilation potentials of different design schemes during the schematic design phase. For example, it would be very useful to have a graphic-oriented tool (not a spreadsheet) in which the architect could enter variables such as building envelope shapes, window opening sizes and configurations, or varied building orientations. A basic airflow prediction would utilize local site climate data to assist designers in determining the exterior and interior airflow patterns relative to the temperature and pressure data. The constraint in such a tool is the potential danger of a "garbage-in, garbage-out" process; in other words, if input information is too simplified, the results or data are irrelevant or not useful. Exploration in computer airflow analysis is being conducted at MIT's Building Technology Department, making it an appropriate environment for further research into the development of an architect-oriented interface.

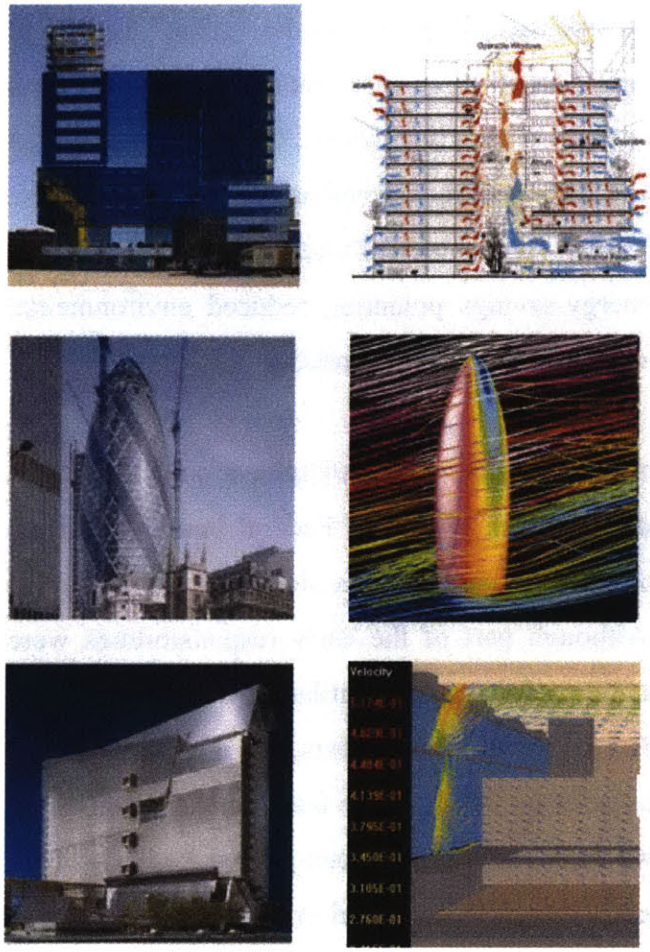
The future of post-occupancy evaluations can be influenced by a few factors. First, in order to acquire funding, the public must deem healthy, low-energy buildings a priority. Public demand has the potential to motivate appropriate legislation and financial support. Ecological building rating systems are one approach to encourage public awareness. In addition, changes to the fee structures of engineering services should reflect the environmental impact of a building's design.

3A. Case Studies Introduction

The three case study buildings illustrate principles of environmentally and socially-responsible large office buildings employing natural ventilation. The intention of reviewing these three buildings is to understand how the design team created and verified the natural ventilation schemes so that the lessons learned can be applied to future projects. While principles of natural ventilation design are well-documented, the design of a large naturally ventilated building requires extra coordination and communication responsibilities, awareness of current research, and skillful navigation of common obstacles. This text is intended to be a reference on how the design teams executed these ground-breaking buildings and a prescriptive commentary on the future of the design profession relative to the large naturally ventilated building typology. The topics discussed include fostering multidisciplinary collaboration, garnering client support, evaluating simulation methods, navigating value engineering, and encouraging post occupancy evaluation, all in the context of the architect's role and influence.

The three buildings took different approaches to the natural ventilation design and corresponding form. The SF Federal building utilizes cross ventilation in a thin rectangular mass flanking the wind. The Genzyme building massing is essentially a square block with a central atrium that utilizes the stack effect. The Swiss Re building is significantly taller than the two, with spiraling atria linking multiple floors on the periphery where ventilation is driven both by stack effect and wind-induced pressure differential. (see Figure 1)

The case studies are accompanied by a diagram highlighting those events considered by the author as critical to facilitating the natural ventilation design. These diagrams are placed at the conclusion of each case study. The key players, events, and decisions are highlighted as a visual representation of the natural ventilation design process. The arrows are located relative to the project timeline. The color and width of the arrows denote the parties and intensity of effort respectively.



Genzyme building
Architect: Behnisch & Behnisch
M. Engineer: Buro Happold

Swiss Re building
Architect: Foster & Partners
M. Engineer: Hilson Moran

San Francisco Federal
Architect: Morphosis
M. Engineer: Arup
Research: LBNL & UCSD

Figure 1: Case study buildings *(Sources listed above)*

The three clients (two private, one governmental) all supported the "green" aspects of design, but with varying levels of initiative. In all three case studies, the design began with a request for some aspect of green design in the client brief. The design of the San Francisco Federal building and Genzyme building were selected as competition winners. In all three cases, the clients recognized that an environmentally-sensitive building was in the best interest of their companies: energy-savings potential, reduced environmental impact, public relations promotion, and comfortable, healthy workers.

The case studies also exemplified the methodology of architect/engineer collaboration in the early stages of design. In the case of the San Francisco Federal building and the Genzyme building, the architects did not enter the competitions alone, but rather teamed up with the engineers at this phase. Although part of the early responsibilities were determining if the site and climatic conditions for natural ventilation were appropriate, this information is fairly straightforward and covered in other texts, and therefore will not be the focus of this research. Instead, the inner-workings of the team's collaboration will be examined. Specific, defined objectives and familiarity between parties are some of the variables in the initial stages that assisted a straightforward and proficient collaboration. The multi-disciplinary collaboration resulted in the integration of building systems which prevented the green components from being seen as separate, superfluous, or expendable.

In order to evaluate the natural ventilation schemes, the three projects took different approaches. The SF Federal building was designed with the assistance of research institutions and federal grants to support the simulation work. Genzyme was designed based on the design team's recent experience with similar projects and did not involve simulation work. The Swiss Re's airflow evaluation was executed by a private company specializing in simulation. Readers most interested in the assumptions and variables of the simulation work should refer to the description of the SF Federal building.

It is also important to examine how the proposed natural ventilation designs are working in "real life." The data for this is limited because of the recent nature of these projects, but it is interesting to examine how the monitoring process is set up, who is responsible, and how it is funded. As discussed in Chapter 2, a naturally ventilated building often operates sub-optimally for any number of reasons including inefficient design, mechanical breakdowns, and improper operation. Readers most interested in the post-occupancy evaluation information should refer to the Genzyme building's commentary. Through understanding the approaches taken in these three case studies, one may apply relevant principles to future work.

Acknowledgements

I would like to thank and acknowledge the professionals who were so generous in sharing their time and insight to clarify and discuss this research. Discussions were held in their offices, at the building site, and through phone and email.

San Francisco Federal Building:

Tim Christ, Project Manager, Morphosis
Erin McConahey, Mechanical Engineer, Arup
Philip Haves, Building Technologies, Lawrence Berkeley National Laboratories

Swiss Re building

Rob Harrison, Associate Partner, Foster and Partners
Matthew Kitson, Divisional Director Environmental Modeling Group, Hilson Moran
Ben Abel, Senior Environmental Engineer, Hilson Moran Partnership Ltd.

Genzyme building

Stephan Behnisch, Architect, Behnisch, Behnisch & Partners
Rick Ames, Architect & Principal, Next Phase Studio
Byron Stigge, Engineer, Buro Happold
Steven Driver, Engineer, Genzyme

3B. San Francisco Federal Building

SF Federal building quick facts:

Architect: Morphosis, Los Angeles

Client: United States General Services Admin.

Collaborators: Ove Arup & Partners, structural, mechanical, & electrical; Horton-Lees-Brogden, daylighting; Lawrence Berkeley National Laboratories, simulation; Univ. of California San Diego, simulation; Brian Kangas Foulk, civil; Smith Group Inc., Executive architect; Richard Haag Assoc. w/ JJR, landscape; Dick Corp. w/ Nibbi Brothers, general contractor.

Location: San Francisco, California, USA (urban)

Major materials: exposed cast-in-place concrete, perforated stainless steel, glass

Total floor area: 605,000 sq. ft.

Natural ventilation strategy: The 18-story tower uses cross ventilation across the narrow 19 m floor plate and a concrete structure for thermal mass.

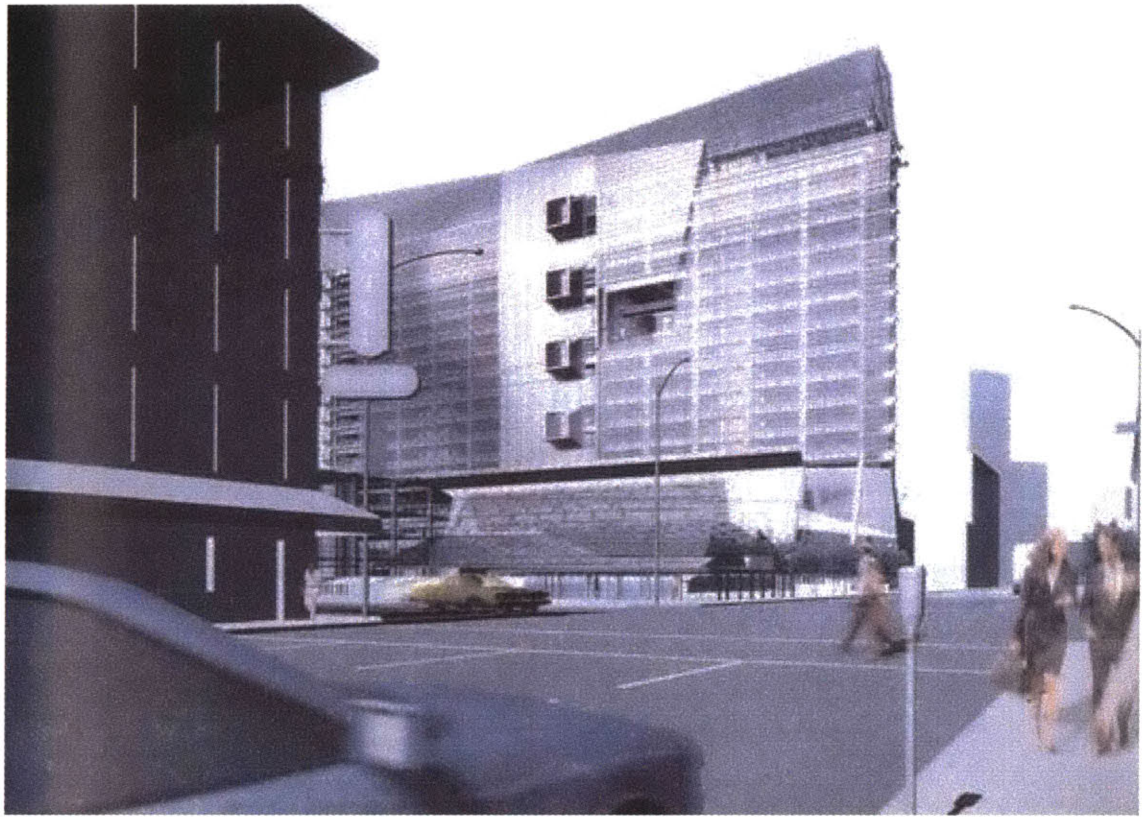


Figure 2: 18-story tower, SFFB. *(GA document 2002)*

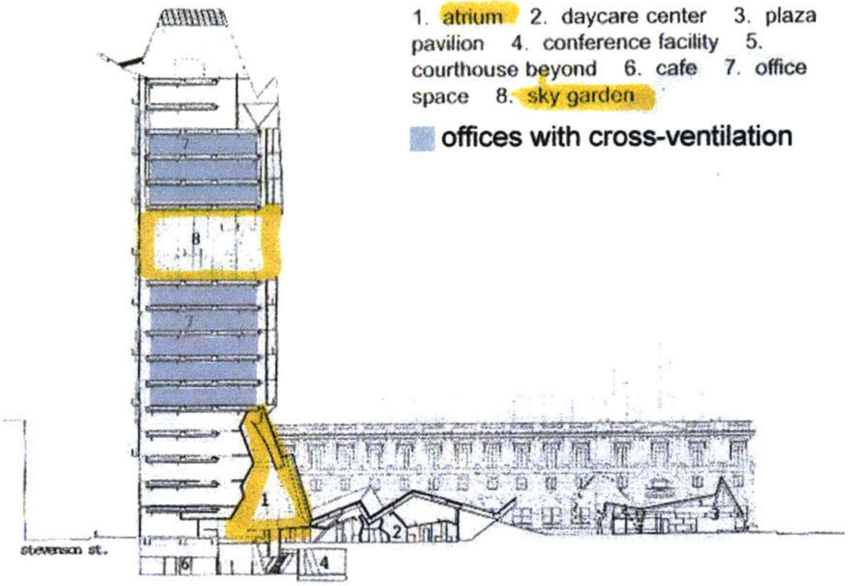


Figure 3: SFFB section drawing shows cross-ventilation above 5th floor *(modified from GA document 2002)*

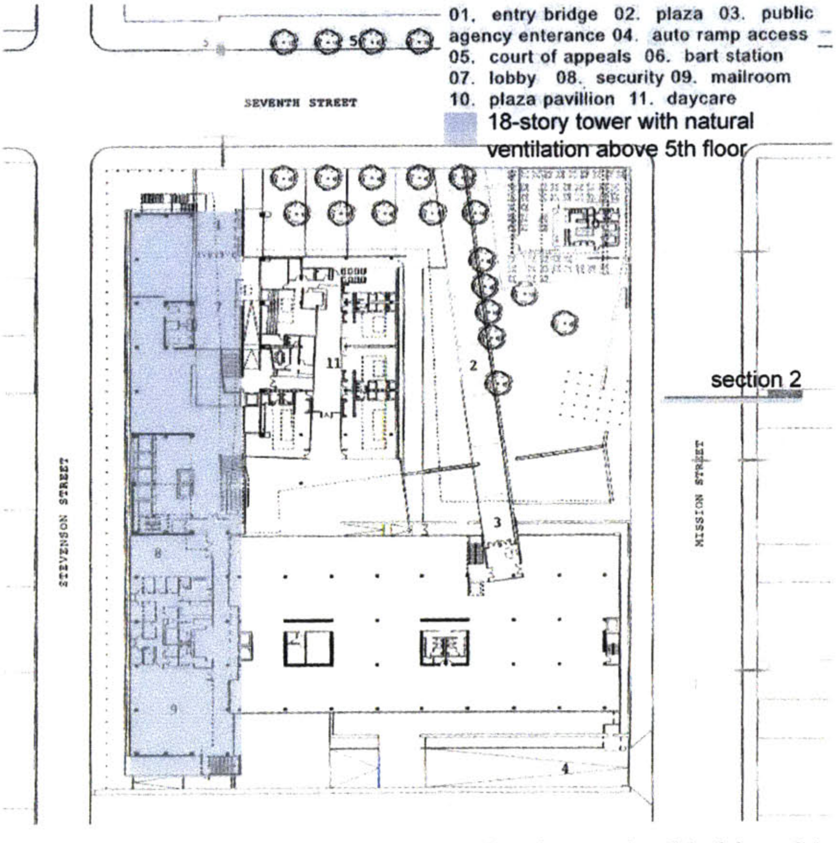


Figure 4: SFFB plan highlights naturally ventilated tower *(modified from GA document 2002)*

3B.1 Establishing design objectives

The collaborative meetings with all consultants in the initial phases of design were crucial to identifying the opportunities and constraints of the site and establishing the objectives driving the SF Federal building's design. At the table were three mechanical and structural engineers from Arup, a daylighting expert, and the architecture design team. The temperate climate, site orientation, and local wind conditions allowed the team to "pursue an overall design that deemphasized the use of air conditioning and maximized daylighting."[ix] At the first month, no computer tools were used and the team relied on their site observations and intuitions to develop a building massing consisting of a thin narrow slab flanking the wind. (see Figure 2) The 18-story tower uses cross ventilation across the narrow 19 m floor plate and a concrete structure for thermal mass. (see Figure 3 & Figure 4).

In addition to the climatic site opportunities, programmatic constraints influenced the natural ventilation design. The amount of open-plan versus enclosed offices informed the section drawing, locating cross-ventilated open-plan offices on the perimeter and the mechanically-cooled central enclosed offices. The central, enclose spine program includes cellular offices, conference rooms, restrooms, and social areas. It was hypothesized that the airflow would enter the NW windows, flow over the central enclosed offices, and exit through the SE windows. (see Figure 5) This move is in contrast to typical office hierarchy where the private, more prestigious offices are located at the window; the decision required explanation to the client which was accepted. The other programmatic constraint was the federal security requirement for the first five floors to be sealed (no operable windows). The solution here was to locate many of the spaces with cooling needs on those lower mechanically cooled floors.

It is significant to note here that of the three case studies in this thesis, the San Francisco Federal building is the only project in which some offices are *never* mechanically conditioned. This reliance on natural ventilation implies a much more stringent testing/evaluation process because there is no back-up mechanical mode. The scale and location of the SF Federal building allowed the choice to exclude mechanical backup in select spaces whereas the more extreme Boston climate and significantly larger scale of the Swiss Re did not permit the omission of mechanical systems in occupied spaces.

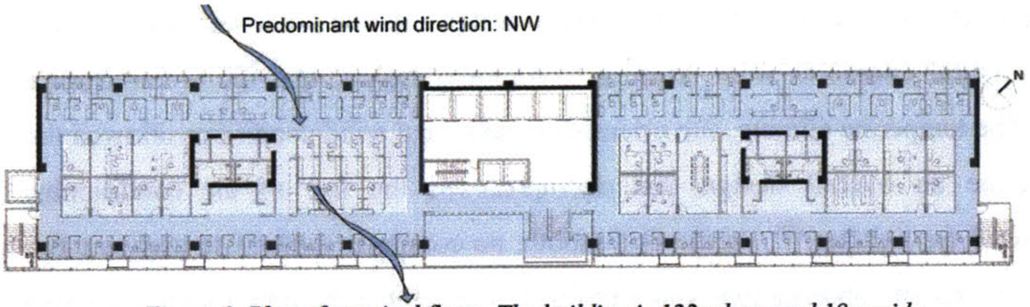


Figure 1. Plan of a typical floor. The building is 122m long and 19m wide.

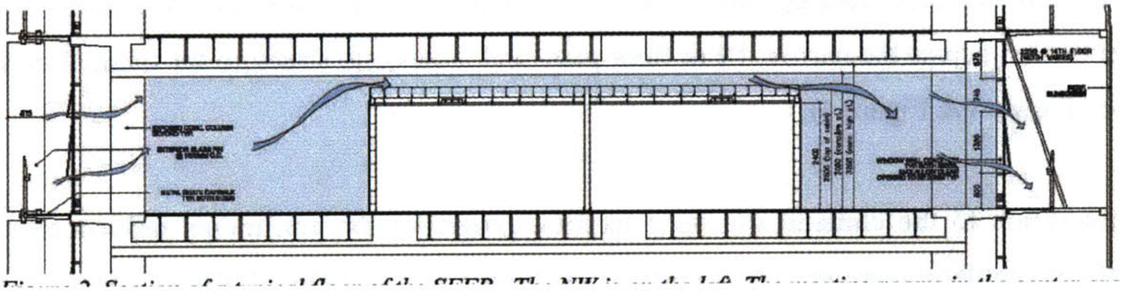


Figure 5: Plan and section of a typical floor plate shows cross-ventilation for perimeter open-plan offices and mechanical cooling for the central enclosed offices. (*Source:* m*odified from Haves 2003).*

The depth of the naturally-ventilated spaces was dictated by the California Energy Efficiency Standards which defined the depth of a single-sided naturally-ventilated space at a six meter distance from the window. In addition, the same code mandated 5% opening area on the façade.

At this time, Arup's role was to confirm the design team's assumptions, particularly about reliance on environmental conditions. The team needed to confirm the diurnal temperature difference which verified that night cooling was a logical solution that should be pursued. In addition to the airflow, cooling was provided by the concrete structural slab which has "a cast-in-place sinusoidal waveform, 250 mm. deep" which acts as the thermal mass.[x] Arup was also providing confirmation that the hot summer temperatures would be offset by high velocity winds required to drive the cross-ventilation.

3B.2 Simulation: The role of LBNL, UCSD, and RWDI

Once the main concepts of the project had been established, the design team sought the confirmation that their ideas about natural ventilation in the open-plan office areas would work in practice. In order to evaluate their design schemes, the design team, led by architect Tim Christ of Morphosis and engineer Erin McConahey of Arup, teamed up with research institutions Lawrence Berkeley Laboratories (LBNL), University of California San Diego (UCSD), and engineering firm RWDI. The primary researchers working on the project included Phil Haves of LBNL and Paul Linden from UCSD.

3B.2.1 Simulation: Collaboration with research institutions

The three collaborators engaging in simulation include LBNL, UCSD, and RWDI. LBNL's simulations tested the comfort conditions using EnergyPlus for airflow and energy modeling and COMIS for multi-zone airflow modeling. UCSD used computational fluid dynamics analysis to fine-tune the apertures and evaluate furniture placement. RWDI conducted wind tunnel tests to determine pressure coefficients for use in the computer models. The inclusion of research institutions in addition to Arup's core involvement was beneficial because LBNL and Arup, being autonomous groups, acted as a peer review for each other. Arup's engineers, "Erin McConahey and Michael Holmes provided assistance and advice [to the researchers] at various stages of the work."[xi]

The collaboration of an architecture firm with research institutions for ventilation analysis is rare in standard architecture practice. The conditions that set the stage for this collaboration included (1) the need for confirmation of comfortable conditions and (2) the pursuit of funding for the simulation work.

Since the project budget did not account for simulation fees, Morphosis pursued a grant through the Department of Energy's (DOE) Federal Energy Management Program to fund LBNL's work that supplemented Arup's work on the core HVAC system. Chartered in 1973, the program's objectives are described on their website as,

> *"The Department of Energy's Federal Energy Management Program (FEMP) works to reduce the cost and environmental impact of the Federal government by advancing energy efficiency and water conservation, promoting the use of distributed and renewable energy, and improving utility management decisions at Federal sites."*[xii]

This raises the question of why the design team chose to work in partnership with the research laboratory as opposed to asking Arup to do the simulation. As Arup engineer Erin McConahey explained that the collaboration with LBNL was a result of "pre-existing relationships that led to the successful acquisition of the grant." Because LBNL is a research laboratory of the DOE, the "grant was given on the basis of the building being essentially a 'test case' for the LBNL software, as well as benefit to the actual GSA project being built. The UCSD work was a subcontract under the umbrella LBNL contract ... Arup did do parallel simulation work to perform a quality assurance check on the LBNL original work, as the LBNL software was still in development at the time and did have some bugs."[2]

Communication between Morphosis, Arup, and LBNL was facilitated by LBNL's written report(s) describing the simulation set up, the findings, and the suggestions to change the design to improve performance. The architect's objective was to be able to show the client that there will be few days when the building is too hot.

3B.2.2 Simulation Objectives: Determining building comfort with Energy Plus

"Within the first month of preliminary design, the team recognized that more sophisticated modeling tools were required to fully understand the variables involved in the application of the natural ventilation concepts."[xiii] The question of how to best provide comfortable conditions had implications on the architectural form, namely the articulation of the southeast facade. The design team consisting of Morphosis and Arup did not have the budget to quantitatively evaluate and compare the design schemes, and collaboration with LBNL and application for federal funding informed the design team and allowed them to move forward with the best solution. The design team explored a

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[2] Email correspondence with Erin McConahey, May 2005.

few different design schemes for the southeast facade before arriving at the solution of the full-height glazing with sunscreen, including ideas like a double façade or stacks to assist the ventilation. These schemes were compared on the basis of the comfort conditions they produced. At the same time these schemes were under comparison, researchers were simultaneously making efforts to calculate the thermal mass, to improve the shading, and to improve the accuracy of the boundary conditions.

By April 2001, Phil Haves at LBNL had tested five different design schemes affecting the natural ventilation design. He was using (and at the same time refining) the then new Department of Energy (DOE) program, Energy Plus. This program was chosen at the time because as Erin McConahey of Arup describes, "other energy-simulation programs can't deal with the natural ventilation issues. The combination of airflow and energy modeling in a single package not only allowed us to predict energy performance, but also to calculate surface temperatures, track air change rates, and predict thermal comfort."[xiv] It can be assumed that as software development continues, more companies will tackle these issues.

The in order to satisfy the thermal comfort conditions, the first rounds of simulations addressed the following questions:

1. *"Is there a need to use buoyancy effects arising from inside-outside temperature differences to supplement the wind?*
2. *If there is such a need, is the stack-driven flow resulting from the use of high and low openings within the height confines of a single floor sufficient, or are sources of additional buoyancy, such as external chimneys on the SE façade, required to give acceptable thermal performance?"*[xv]

The five schemes under evaluation had variation in window opening placement, option with or without chimneys, and comparison of wind versus buoyancy-driven forces. (see Figure 6)

Scheme 1: *"**symmetrical openings, wind** - 0.33m high openings along both the NW and SE facades at the same height. The wind speed used is that expected for the ground floor of a building in an urban environment with no local obstructions. Since the openings are at the same height, there is no buoyancy-driven flow."*

Scheme 2: *"**high and low openings, no wind** - 0.33m high openings along both facades, down to floor level on the NW façade and up to ceiling level on the SE façade, which produces an internal stack; there are no wind effects."*

Scheme 3: *"**high and low openings + chimney, no wind** - 0.33m high openings along the NW façade, chimneys on the SE façade 1m x 3m in cross section, spaced at 9m intervals, discharging 6.54m above ceiling height; no wind effects"*

Scheme 4: *"**high and low openings, wind** - 0.33m high openings along both facades, down to floor level on the NW façade and up to ceiling level on the SE façade. The wind speed used is that expected for the ground floor of a building in an urban environment with no local obstructions. The flow is produced by a combination of wind and internal stack effects."*

Scheme 5: *"**high and low openings + chimney, wind** - 0.33m high openings along the NW façade, chimneys on the SE façade 1m x 3m in cross section, spaced at 9m intervals, discharging 6.54m above ceiling height. The wind speed used is that expected for the ground floor of a building in an urban environment with no local obstructions. The flow is produced by a combination of wind and internal and external stack effects."*[xvi]

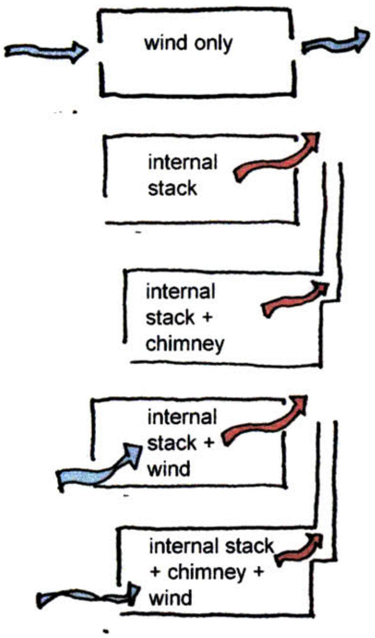

Figure 6: Schematic representations of the 5 models tested in Energy Plus *(drawn by author)*

3B.2.2.1 Setting up the Energy Plus simulation

The audiences less-experienced with these tools will benefit from the following short description of how the models were set up and what assumptions were made. Since architecture students and practicing architects do not typically have training in setting up and running a these types of simulations, I have chosen to explain the process in detail here. The intent is that an architect can use this section to better understand the abilities and constraints of the airflow and energy modeling used in the SF Federal building. This knowledge should facilitate dialogue with an architect's own engineers in future projects. Building services engineers, who probably have a better understanding of the tool's constraints and abilities, may find this section useful as a basis of comparison to their own projects.

The five Energy Plus models previously mentioned were set up as a series of zones with the following assumptions. (see Figure 7)

> *"One 9m section of one open plan office floor was modeled as a single thermal zone. The thermal chimney, when present, was modeled as a second thermal zone. A discharge coefficient of 0.5 was assumed for each opening ... and pressure coefficients were estimated from data in Chapter 15 of the ASHRAE Handbook of Fundamentals... Later runs used pressure coefficients measured using a scale model in a wind tunnel... The different ventilation strategies were simulated for the period of April 1 to October 31 of the TMY2 composite weather year for San Francisco International Airport. The windows are opened whenever the inside air temperature exceeds both the set-point and the ambient temperature."*[xvii]

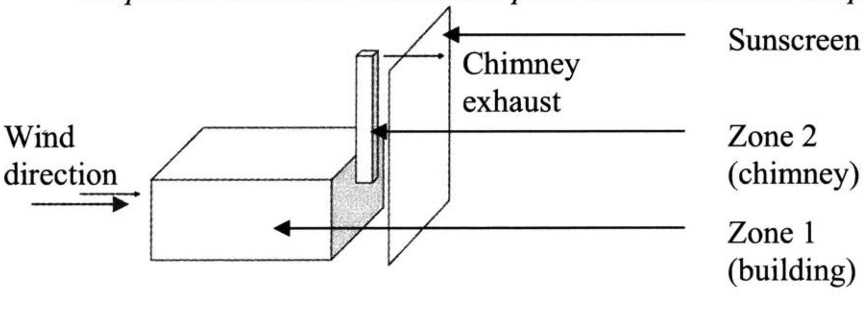

Figure 7: Energy Plus model includes one floor, external chimney, and sunscreen *(Source: Haves 2003)*

How did the team determine the wind data to use in the simulation? The team compared "measured wind regimes at the building site in downtown San Francisco and at the airport, [indicating] the wind speed and direction at the gradient height of the atmospheric boundary layer at each location are not significantly different." To account for the urban terrain, the team assumed a wind velocity profile exponent of 0.14.[xviii]

3B.2.2.2 Simulation: Interpretation of results

The obvious objective of the simulation was to determine if the people working inside the building would be comfortable during the warmer summer months. In order to do this, one must define what is considered comfortable as well as how often the building does not fall within this range. To do this, the client agreed to use the adaptive model of comfort standards (Brager and de Dear 2000) which was then under development but has since been adopted by ASHRAE Standard 55.[xix] Using these standards, the warmest acceptable temperatures are 79-82°F (26.1-27.7°C). The EnergyPlus model was used to determine how many degree hours above various temperatures could be expected. (see Figure 8). This table shows with purely wind-driven ventilation, the inside temperature will be between 72-75 °F for the majority of the year. Only 13 days will be above 78 °F.

Base temperature (°F)	**Wind only**	**Internal stack**	**Int & ext stack**	**Int stack + wind**	**Int & ext stack + wind**	**No ventilation**
72	288	507	432	279	285	14561
75	80	118	103	76	76	8894
78	13	25	19	11	12	4284

Figure 8: Degree hours above certain base temperatures. *(Source: Haves, 2001)*

> *"The main conclusions [of the EnergyPlus simulations] are:*
>
> 1. *Wind-driven night ventilation produces reasonable comfort conditions during the day for all but a few days of a typical year.*
> 2. *Internal stack-driven night ventilation resulting from low level openings on the NW and high level openings on the SE is less effective than wind-driven ventilation, resulting in internal temperatures on hotter days that are ~1°F higher than for the wind-driven case.*
> 3. *A combination of wind-driven and internal stack-driven ventilation produces a modest improvement in performance compared to the wind only case. The contribution of internal stack may be more significant if/where there is significant reduction is wind pressure due to shielding by adjacent buildings.*
> 4. *Addition of external chimneys does not improve the performance of the combination of wind-driven and internal stack-driven ventilation, and may be slightly counter-productive, due to the increased flow resistance caused by the chimney. In the absence of wind, addition of external chimneys helps the internal stack somewhat."*[xx]

In addition to measuring the daily temperatures using TMY2 composite weather data, the team also considered the hottest conditions using historical weather data. The performance of the naturally ventilated space was modeled using both a 'worst-case scenario' and then a more typical warm day. The more extreme scenario was modeled after weather data from 1970 which involved three consecutive hot days. The implications of the sequence of hot days results in ineffective night cooling, and uncomfortable temperatures reaching 80°F. (see fig. 8) The model of the typical warm weather scenario results in internal temperatures of about 77°F which is more acceptable.[xxi] (see Figure 9 & Figure 10)

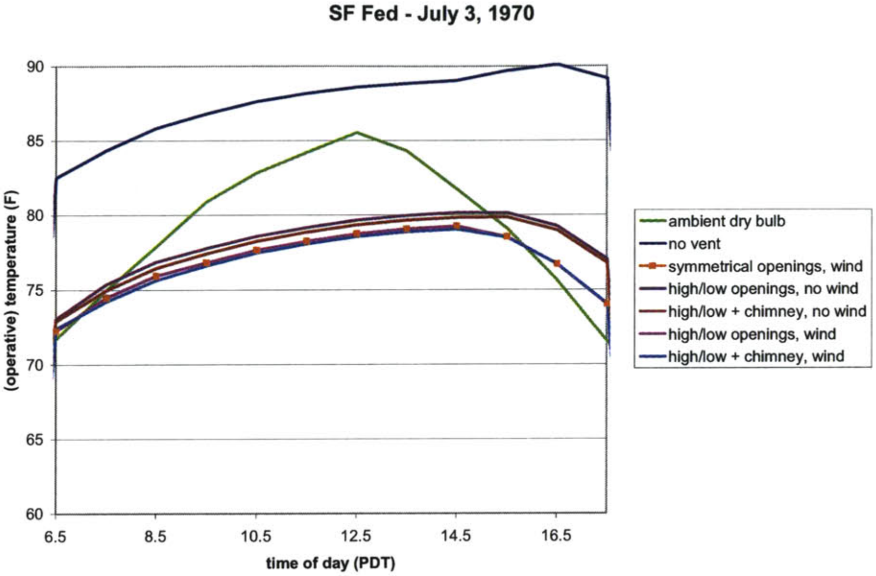

Figure 9: Performance on the third of a sequence of hot days from historical weather data, July 1970 *(Source: Haves 2003)*

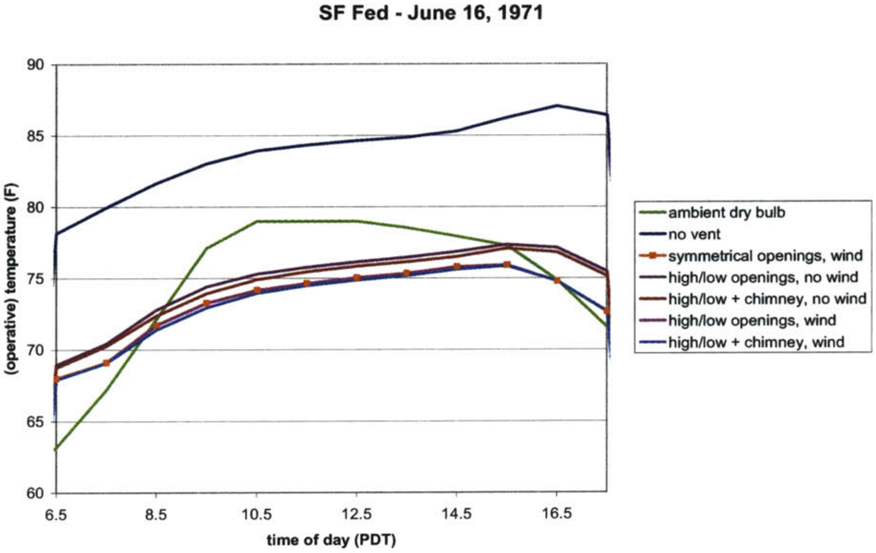

Figure 10: Performance on a more typical warmer day *(Source: Haves 2003)*

3B.2.2.3 Conclusions of EnergyPlus modeling

The conclusions from the Energy Plus models were written up in a formal report communicating to the design team the recommended strategy of wind-driven ventilation. This recommendation is crucial to the architect because it is something that could not have been decided on an intuitive basis, and has a considerable impact on the building form. A quote from the report describes the basis for the recommendation:

> *"A purely wind-driven strategy was selected for the building, based on the following results of a design analysis using Energy Plus:*
>
> 1. *Natural ventilation is able to produce a level of thermal comfort that is likely to be acceptable to the occupants for all but a modest number of hours in a typical year.*
> 2. *Wind-driven ventilation slightly outperforms buoyancy-driven ventilation for the same opening sizes for this particular site.*
> 3. *On all but a few days, the nocturnal cooling of the building has to be limited in order to avoid uncomfortably cool conditions at the start of occupancy. The cooling performance of the building is then limited by the available thermal capacity and the effectiveness of the solar control, particularly on the NW façade."*[xxii]

3B.2.3 CFD simulation and UCSD's role

The second type of modeling used to evaluate the SF Federal building was the computational fluid dynamics studies (CFD). Although Paul Linden at UCSD is known for his work with water bath models, the simulation work done for the SF Federal building was purely computational. The objective of the computational fluid dynamics studies (CFD) was to refine the design and build upon the work of LBNL. The team used the program PHOENICS for the CFD studies. It is interesting to note the scales at which CFD was used in the project: varying from the entire width of the floor plate to the window's edge.

The use of CFD "provided predictions of the cross flow ventilation airflow pattern, the maximum velocities in the occupied volume of the workspace, and the ventilation efficiency and ventilation flow rates for variable wind conditions. The configuration of the ventilation apertures in the façade and the office furniture design were tuned as a consequence of this study."[xxiii] The design was influenced by the CFD studies in the following ways: [1] to confirm the use of thermal mass for night cooling, [2] to better direct the flow from the operable windows, and [3] to reduce the number of operable windows. There physical implications of this were maintaining the concrete structure, designing flow deflector at the window's edge, and greatly reducing the cost of operable windows in the façade.

In addition, the CFD airflow study provided a basis for the design and testing of the control strategy for the building management system (BMS) controlled top windows. UCSD tested some 'dry runs' on the controls sequence before Arup wrote the commands, allowing the building to breathe in response to environmental conditions.

3B.2.3.1 Setting up the CFD simulation

In order to understand the applicability to future projects, it is important to understand what assumptions were made in the CFD models and how the researchers determined that the models were satisfactory. The scope of the CFD models included modeling cross ventilation across the width of a floor plate, for ¼ of a typical floor plate area, with two windows on each façade. The model included furniture and the concrete ceiling with a sinusoidal cross-section. The model included outside conditions as provided by RWDI's wind tunnel tests and tested variable wind speeds as well.

For future projects, one may be interested to know the criteria for this model to be considered accurate and to have run a sufficient number of iterations as described by the researchers.

> *"Simulations were considered converged when the normalized residuals were smaller than 10^{-3} and the solution field was stable: i.e. the values did not change by more than 10^{-7} (relative change) between iterations, and showed no visible fluctuation or changes after hundreds of iterations. The effects of turbulence were modeled using the standard k-ϵ model. Results of simulations for different flow rates showed a linear variation of the air speeds in the room with inlet speed, as expected."*[xxiv]

3B.2.3.2 Interpretation of CFD results

The CFD results appear to confirm the design's effectiveness in two ways. First, the airflow follows the ceiling and exits through the SE bay, which suggests that the cool night air will effectively draw the heat out of the ceiling slab. The second outcome of the airflow staying near the ceiling is the avoidance of high air velocities in the occupied zone during the day.

"The first simulation revealed that the expected problem area behind the service core is well ventilated, showing no significant stagnation." (see Figure 11) The second simulation compared that the user-operated windows position being open or closed did not "significantly affect the airflow in the occupied region." (see Figure 12) This is worrisome because without environmental feedback, users may make poor decisions about window operation. This led to the design of a flow deflector at the edge of the user-operated window to better direct the airflow. This flow defector was also tested with CFD. (see Figure 13)

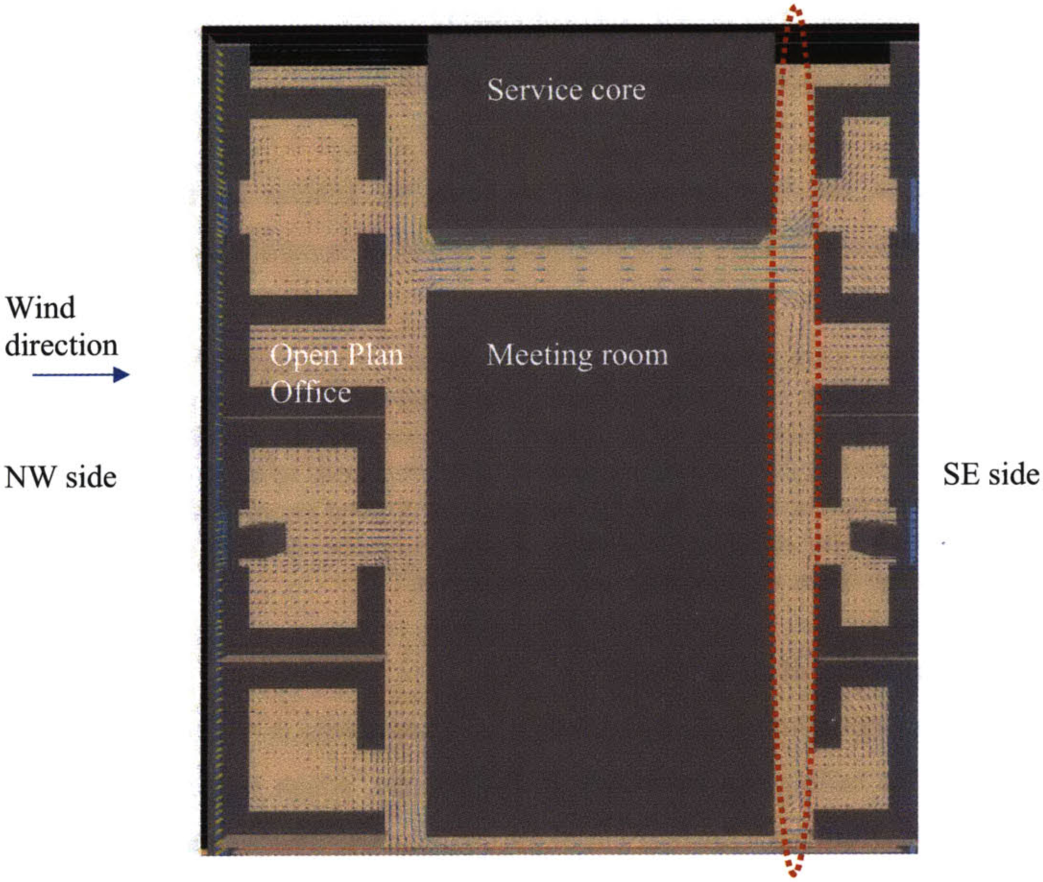

Figure 11: CFD model of cross-ventilation in plan of a typical floor plate shows little stagnation in the area circled in red - the SE open plan offices. *(Source: Haves 2003)*

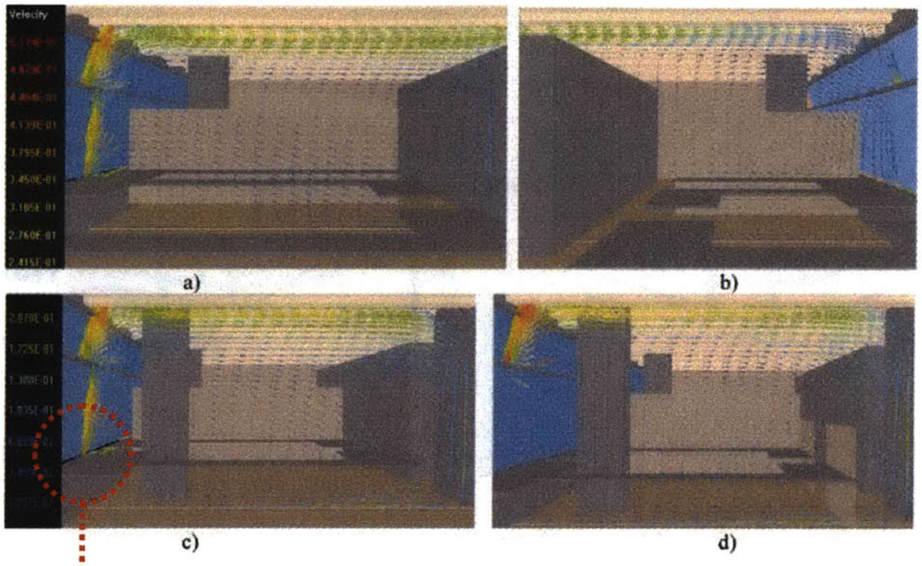

Figure 12: CFD model of cross-ventilation in section shows the lack of airflow in the occupied zone from the lower, user-operated windows. This resulted in the development of a flow deflector. *(Source: Haves 2003)*

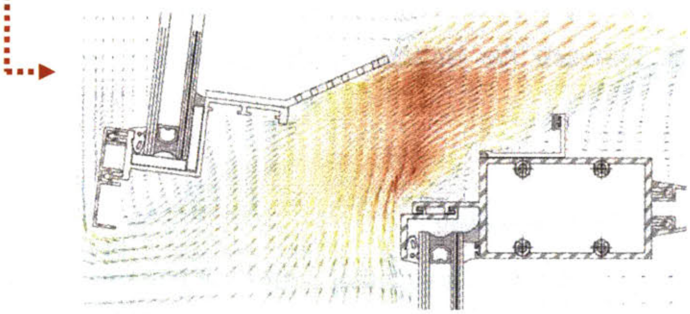

Figure 13: CFD simulation shows a side view of the flow deflector designed for the lower, user-operated windows. *(Source: Haves 2003)*

In addition to predicting the airflow in the space, the CFD models were used to determine how to operate the windows most effectively. Five variations of having all windows open, alternating windows open, and windows partially open resulted in a specific strategy. The top windows, which are operated by the building management system (BMS) were found to be most effective in providing air mixing and adequate air changes with alternating open and closed openings. The CFD model with half of the top windows open showed a decrease from 22 ACH to 16 ACH with a 3 m/s wind.[xxv] This decrease was considered acceptable, and had significant impact on the cost of the façade: by cutting the number of motorized windows in half, the cost of the façade could be greatly reduced.

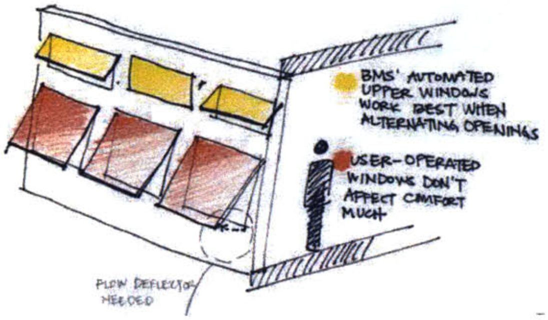

Figure 14: Sketch illustrates the results of the CFD tests which determined that only half of the upper windows needed to be operable. *(sketch by author)*

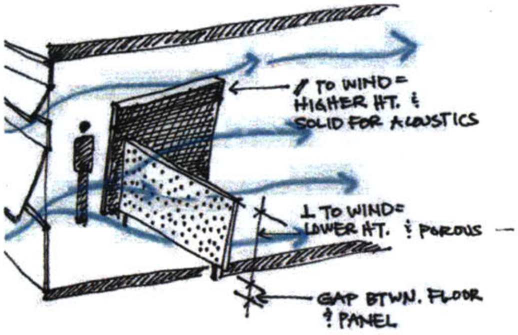

Figure 15: Sketch illustrates the influence of CFD on the furniture strategy. *(sketch by author)*

The CFD models also assisted the team in determining furniture placement and materials. The three resulting strategies were [1] to place solid, acoustic absorbing, taller partitions parallel to the wind; [2] to locate porous, lower partitions perpendicular to the wind; and [3] to maintain a gap between the bottom of the panel and the floor to allow for airflow.[xxvi]

3B.2.3.3 Conclusions of CFD modeling

The CFD modeling proved airflow behavior that could not have been intuitively guessed or assumed by the design team without the use of such tools. The major impact of CFD on the design is the reduction in operable windows, the design of a flow deflector, and creation of a furniture strategy. This resulted in cost savings on the façade, better airflow, and improved occupant satisfaction. In addition, the CFD was used to verify the effectiveness (avoiding high velocities and stagnation) of the airflow patterns at different wind speeds.

3B.3 Appealing to the client

3B.3.1 The client brief & establishing objectives

The client, the GSA, called for a 'model building' as part of the Design Excellence Program. Among a number of other objectives, the Design Excellence Program specifically mentions its commitment "to incorporating principles of sustainable design and energy efficiency into all of its building projects."[xxvii]

Before the SF Federal Building project, the GSA commissioned Morphosis to do early studies on sustainable strategies applicable in San Francisco. Although Morphosis was awarded the contract in 1998, design of the SF Federal building did not begin until September 2000. Part of the time in between was used to produce a research report "examining principles of energy efficiency that might guide the overall design direction of the project." This study was for internal use in the GSA and defined objectives for the future design of the SF Federal Building. Morphosis teamed up with Alan Locke of I.B.E. Engineering to produce a study addressing "building form, circulation, massing, and the environment of the workplace" which was completed in early 2000. [xxviii] The study concluded that new models for federal architecture should be "informed by a user-centric approach incorporating energy efficient and green policies designed to improve the well-being of users by examining the quality of the workplace and user control of the interior environment."[xxix]

This separate study helped Morphosis frame the interpretation of the contract to emphasize the sustainable agenda. In addition, it is interesting to note the political climate in which this design was evolving: California was then experiencing huge blackouts and energy crisis when electricity rates spiked. Therefore one may assume that the call for energy efficient measures should be well-received. It is also interesting to note that the city of San Francisco announced a new Green Building Ordinance in 2004 (after the design of the SF Federal building) requiring LEED silver ratings for all new projects.[xxx]

3B.3.2 Developing a solution to the brief

Although the client brief called for "sustainable design", the design team still had to defend their definition of the most effective approach to reaching this goal. It should be recognized that while the development of a design solution includes countless factors, this research focuses on those most influential to the natural ventilation design. In searching for the optimal solution for energy savings, San Francisco's temperate climate made natural ventilation a likely option to explore. The form-determining result of the decision to use natural ventilation was a narrow floor plate to allow for cross-ventilation (and daylighting). The narrow, tall building form was also a response to security requirements mandating the bottom five floors to be sealed, limiting any natural ventilation opportunities. If the building sprawled across the site and remained low, the deep floor plate and security requirements would have prohibited the use of natural ventilation. By going tall, the design could take advantage of passive cooling through the use of operable windows (in addition to provide public space at ground level).

In expressing the solution to the client, Morphosis' experience on projects in Europe with similar goals lent confidence to the concepts. The narrow width of the San Francisco building was influenced by Morphosis' familiarity with working with European standards which are more stringent on items such as the distance between an office desk and a window. For the SF Federal building, the team established the target building width to be less than 18 meters. This is in contrast to the U.S.'s standard deep office building where the typical office depth is 40 meters to maximize the envelope to area space.[3] Specific energy-use targets were established as well: to use half the typical office's the Btu/ft^2/year for cooling by taking advantage of the wind and the site. So instead of 55,000 Btu/ft^2, the objective was 27,500 Btu/ft^2.

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[3] Telephone conversation with Tim Christ of Morphosis, April 2005

3B.3.3 Making the case to the client

It was critical that the design team could first justify its environmental goals and second explain how the design would meet these goals. To do this, the team had to describe how natural ventilation would satisfy the comfort standards would be met during the hottest months of the year. In order to do this, the definition of comfort had to be established and accepted by the client. Convincing the client of the merits of the natural ventilation had two aspects: [1] showing that the comfort conditions would be satisfied and [2] proving the economic benefits with a life-cycle cost analysis. To describe the comfort conditions, the team referenced the work by Gail Brager on thermal comfort in naturally ventilated spaces (described in Chapter 1), which was under development, and had not yet been adopted by ASHRAE. In summary, Brager's work shows the larger acceptable range of temperature swings within a naturally ventilated space because of adapted actions and altered psychological expectations. The design team considered the adaptive comfort standards one of the decisive components in their presentations to the GSA in 2001. The GSA's approval of the adaptive comfort standards allowed the design to proceed with the argument that the few days of unacceptably high temperatures were outweighed by other factors such as energy savings and occupant benefit.

It is important to understand that the client, not codes, determines how many hours of uncomfortably high temperatures are acceptable. Therefore, an economic argument for deviating from the typical office building and creating a naturally ventilated building had to be explained. On one hand the GSA was concerned about losing work hours because of uncomfortable conditions. On the other hand, Morphosis explained how the life cycle cost analysis' savings outweighed the few projected lost work hours. Thom Mayne, principal at Morphosis says, "The ventilation system is innovative and will save up to $500,000 a year in energy costs."[xxxi] An obvious lesson for future projects, when appealing to risk-averse clients, the architect should create a case for being concerned about more than just the capital investment. As part of the life-cycle cost analysis, the GSA subcontracted Morphosis to do Maintenance and Operation projections for the building. The results of this analysis showed that the M & O projections were only 1 $\$/ft^2/year$ compared to the standard 1.5 $\$/ft^2/year$. Being one of the largest owners of

U.S. buildings, the GSA has an extensive database on Maintenance and Operations, and therefore recognizes the importance of the M&O savings. For reference, the GSA in this case, consistent with the policy for all federal buildings, hired a separate non-federal entity for M&O as opposed to someone from the design team or client group.

Four months after design began, the team presented its relatively well-developed concepts to the GSA in January 2001. Through a cost model they were able to show that they could decrease the first cost of the HVAC from 17-18% down to 9% of project cost.[4] The implication of those savings meant that the budget could then be applied to the façade options like operable windows, controls (BMS), sensors, etc.

3B.3.4 Navigating the value engineering process

Client review and budget management required a savvy design team to navigate the value engineering process while maintaining the integrity of the proposed concepts. "Morphosis sought to embed the architectural language of the building within the mechanical and structural engineering concepts, inextricably binding each element of the building. This approach was explicitly engaged to deter the possibility that the sustainability goals be abandoned at a later point in the design process through value engineering."[xxxii] In the end, the integrated design objectives were met and the economic goals were satisfied: the SF Federal Building was built for 50 $/ft^2 cheaper than a typical Class A office building.

The collaboration of multiple parties was not only key to navigating the value engineering process, but achieving the desired clean aesthetic as well. The façade design is a good example of how multiple functions can be incorporated in an elegant fashion when each of the parties is present to negotiate the design. The functions of the façade include operable windows, integrated window actuators and trickle vents, finned tube heating convectors, electrical wiring, and trenches connecting to the under-floor plenum. "The architect and window wall consultant worked with the mechanical, electrical and

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[4] Telephone conversation with Tim Christ of Morphosis, April 2005

structural engineers to develop a set of details that would allow the "clean" window wall aesthetic."[xxxiii]

3B.3.5 Concurrent topics relevant to natural ventilation design: shading and life-safety

Two other topics, the sun-shading and life-safety issues, had an impact on the natural ventilation design. More detailed information on each is available in separate reports but their relevance to the passive cooling design is mentioned here.

The design of the sun shading devices is relevant to the natural ventilation performance as it mitigates the heat gain on the façade. The design team's objective was to maximize the glass area on the façade, which would obviously cause problematic solar heat gain without shading. The design team was challenged with creating an effective sun-shading device with desirable and appropriate aesthetic qualities. Simultaneous to the ventilation simulations, daylighting studies were being conducted by consultant Horton-Lees-Brogden. The design solution was to create a variable screen that wraps the entire south-east façade. "During the day, selected panels of the sunscreen move in response to the changing angles of the sun and permitted unobstructed views." On the northwest façade, fixed vertical fins made of laminated translucent glass shade the low-angle sun. "Low emissivity glass was used for the majority of the glazing, achieving a solar heat gain coefficient of 0.37 and shading coefficient of 0.43, while maintaining visible transmittance of 70%."[xxxiv]

The design team also had to address life safety issues in which the main concern was controlling smoke in the event of fire. The solution was to provide means for the windows to automatically close if there is a fire to prevent smoke from spreading to adjacent floors.

3B.4 Chapter Summary

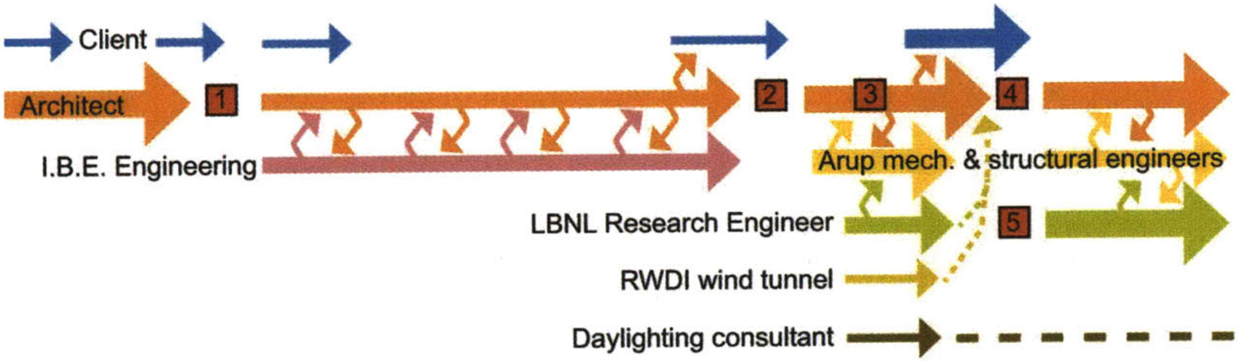
In conclusion, the natural ventilation design of the San Francisco Federal building required a savvy team with knowledge not only of the principles behind the airflow, but awareness of opportunities for funding, collaboration, negotiation with multiple parties, and the organizational skills to see it through. In this case, the simulation was critical because some of the offices are never naturally-ventilated. Therefore ability to prove comfortable temperatures, and awareness of new adaptive comfort standards, enabled the design team to present a convincing case to the client. In addition, the simulation informed decisions about the operable façade, resulting in a reduction in cost. The least technical but most crucial design decision was to engage in interdisciplinary collaboration from the earliest stages of design in order to maximize opportunities for passive systems to be employed.

Figure 16: San Francisco Federal building natural ventilation design diagram (following pages).
(Small image sources: LBNL, UCSD)

Project Timeline for San Francisco Federal building

1998	1999	2000	2001
Morphosis awarded contract	Morphosis researches a new user-centric model for SF Federal building in a report to GSA	Sept: design begins Oct.: researchers collaborate for simulation	Schematic design

Information flow influencing natural ventilation design



GSA requests "sustainable design + energy efiiciency 1

Initial report w/ consultant supports environment + people 2

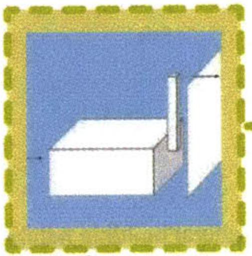
Includes climate analysis

Collaboration to define clear objectives + confirm feasibility 3

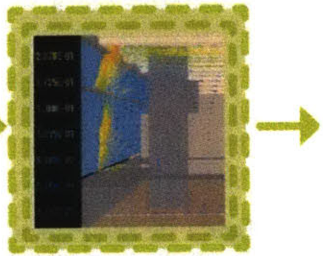
Relevant codes: office depth=6m, 5% openings in facade

Arch. presents scheme w/ adaptive comfort standards and cost analysis 4

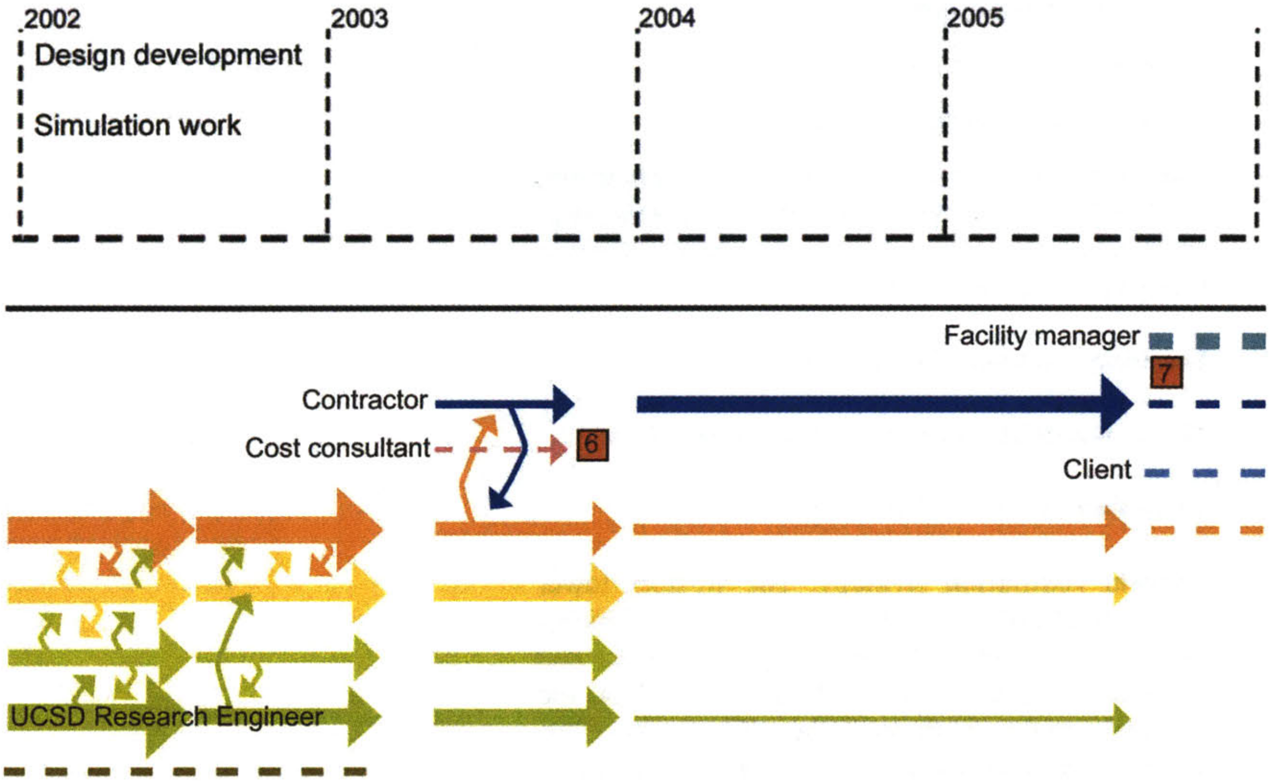
Engineer supports w/ calculations assessing night cooling, wind speeds, + thermal mass.



stacks?



airflow



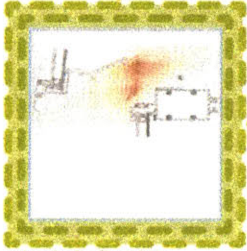
Simulation to evaluate comfort, energy use, and airflow 5

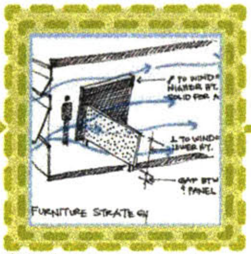
Unfamiliarity with operable facade requires negotiation with cost estimator 6

GSA hires independent facility manager. O+M manual needed. 7

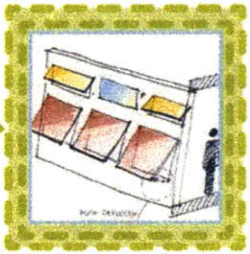
🟥 = critical moments

Simulation not in budget. Applied for federal grant.


wind deflector



furniture strategy


window openings

4. Swiss Re building

Swiss Re building quick facts:

Architect: Foster & Partners

Client: Swiss Reinsurance Company

Collaborators: Hilson Moran Partnership, mechanical and electrical; BDSP Partnership, environmental; Ove Arup, structural; Emmer Pfenninger, cladding consultant;

Location: London, UK (urban)

Major materials: steel diagrid structure, glass

Total floor area: ~500,000 sq. ft

Natural ventilation strategy: The 40-story tower has automatically-controlled windows on the multi-story spiraling atria that use both stack effect and variations in pressure created by the wind on the façade to move air through the office areas. The mixed mode strategy utilizes natural ventilation up to 40% of the year. The deep air cavity and blinds in the façade buffer the outside environment moderate internal climatic conditions.

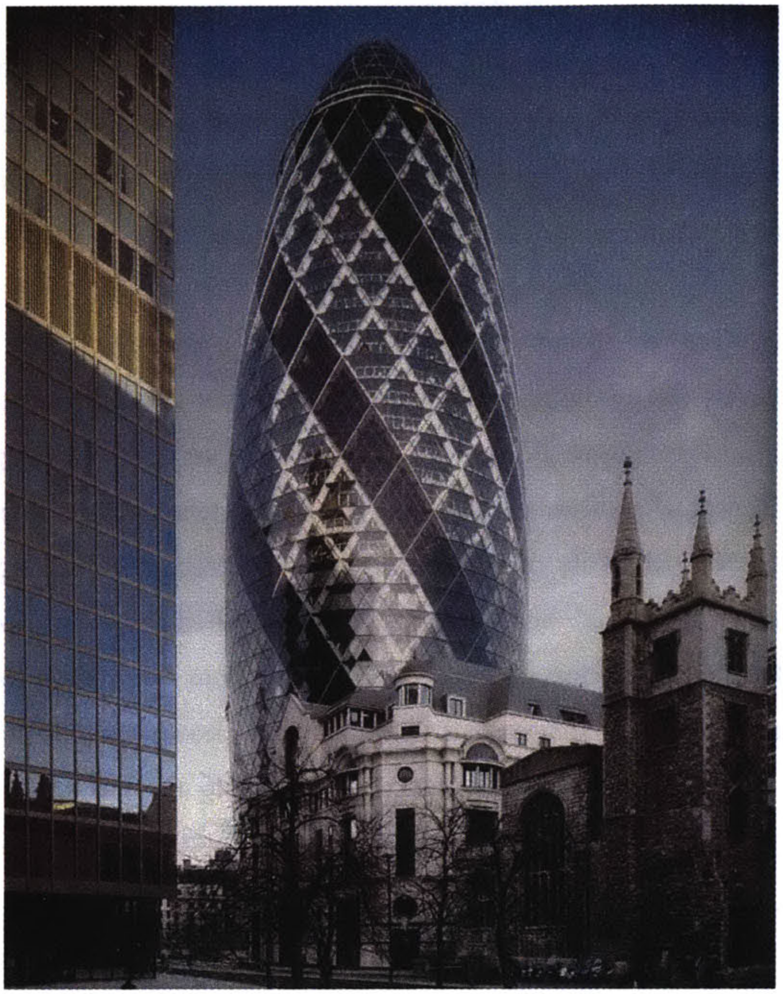


Figure 18: Swiss Re building *(Source: A+U)*

4.1 Establishing design objectives

After the 1992 the bombing of the Baltic Exchange building left the site in need of redevelopment, an existing 1994 design proposal was pushed aside when Swiss Re acquired the site and commissioned Foster and Partners to re-think the site. The architects and engineers were designing the building by 1998, and after a lengthy approval process, the three-year construction began in July 2001. The tapered circular tower resulted from a number of initial design objectives including the desire to create a livable office environment, to use the favorable mild climate to facilitate cooling, and to respond to the local wind conditions. (see Figure 18) The natural ventilation design stemmed from the client's support of environmental goals, the design team's experience in similar issues, and the ability to simulate the conditions in and around the building. While there are many fascinating social and technical aspects of the design and construction of the Swiss Re, the description of the design process here focuses on the factors influencing the natural ventilation scheme with the intent that lessons learned be applied to future projects. The two main components contributing to the use natural ventilation (data now being gathered to confirm the projected use up to 40% of the year) are the façade and atria.

The Swiss Re's main features facilitating natural ventilation, daylighting, and social goals are the spiraling light wells. Although the spiraling form is new to the design team, the concept has longstanding roots in the firm's sky-garden ideas. In describing his design philosophy, Foster writes, "Our buildings have always been driven by a belief that the quality of our surroundings directly influences the quality of our lives...This emphasis on the social dimension is an acknowledgement that architecture is generated by people's needs, both spiritual and material."[xxxv] The desire to create a relationship between nature, work, and social issues is evident in projects as far back as the late 1970's as seen in Foster's collaboration with Buckminster Fuller with their design sketches for the Climatroffice. (see Figure 19) These ideas served as a basis for the design of Commerzbank, which is publicized as the world's first ecological high rise and is an important precedent to the Swiss Re. (see Figure 19) Commerzbank is triangular in plan with a central atrium, two sides of the triangle contain office functions while the third

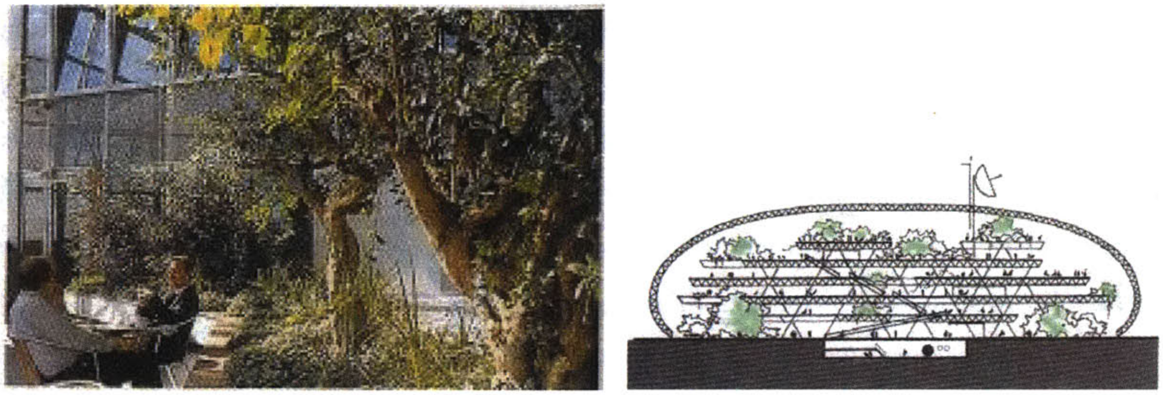


Figure 19: Foster's Climatroffice (right) and Commerzbank (left) ideas of sky gardens precede the Swiss Re building's spiraling atria. *(Source: Amelar)*

houses a garden. “The 4-story gardens spiral around building, bringing daylight and fresh air into atrium which acts as natural ventilation chimney for inward-facing offices.”[xxxvi]

The Climatroffice concepts and the Commerzbank building paved the way for Foster and Partners' to execute their sustainable and social goals in the London skyline. The tapered circular form is derived from the wind conditions at the site where the aerodynamic form reduces the wind loads on the façade while also reducing the pedestrian level winds as compared to a building rectangular in plan. (see Figure 20)

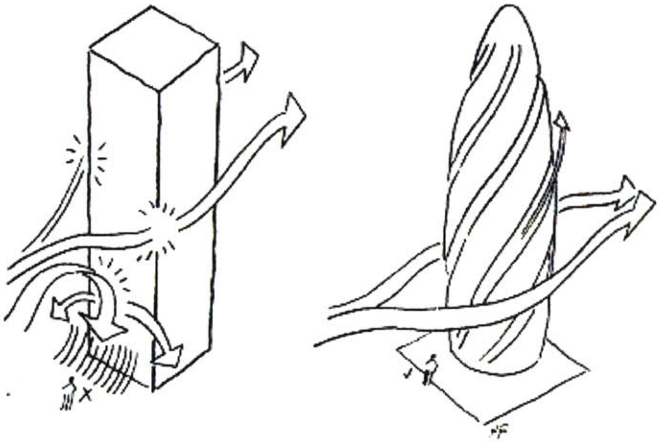


Figure 20: Sketch shows reduction of pedestrian level winds
(Source: Foster)

The floor plan predictably houses an enclosed structural core and locates offices near the perimeter. As compared to the San Francisco Federal building where the distance for the single-sided natural ventilation office space is limited to 6 meters, the Swiss Re's distance from window to core is 15 meters. The largest floor plate, the 17th floor, is 57 meters wide. The triangular wedges cut out of the circular plan are rotated in plan 5° on each floor producing the spiraling light well voids which increase the perimeter area and provide a visual connection between floors. (see Figure 21) These voids span either six or two floors. (see Figure 22) The balcony edges lack the glass wall, allowing air to move into the office space. (see Figure 23)

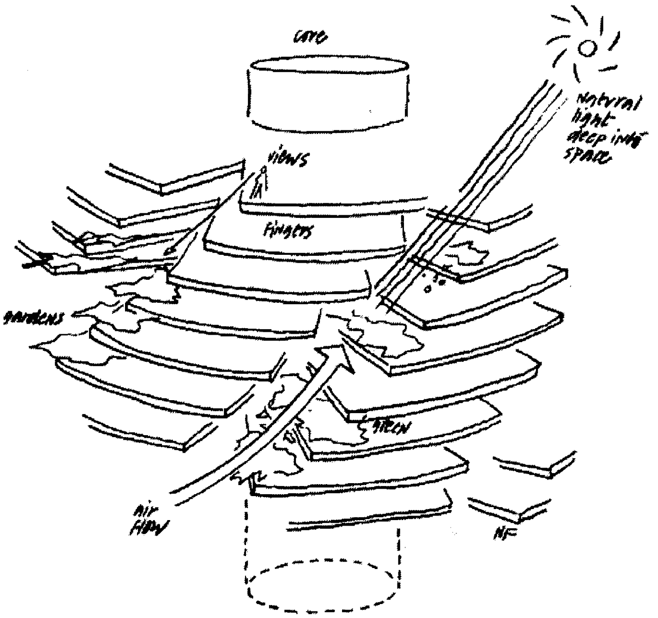


Figure 21: Initial sketches describe the air and light penetration in the spiraling atria. *(Source: Williams, 2002)* Note that the atria's spiral direction was later reversed in response to computer simulation results.

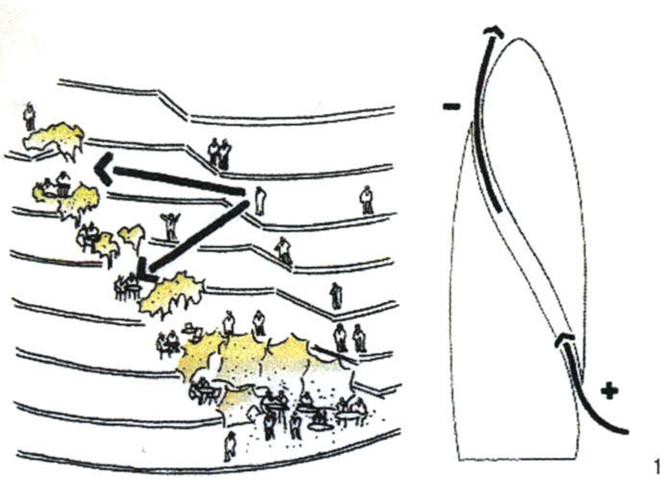


Figure 22: : The concept drawing for SRB shows multi-story spiraling sky gardens which inspired the spiraling atria, two of which span six-stories each. The atria use the wind-created pressure differentials on the façade to move the air through the building. *(Source: Amelar, 2003)*

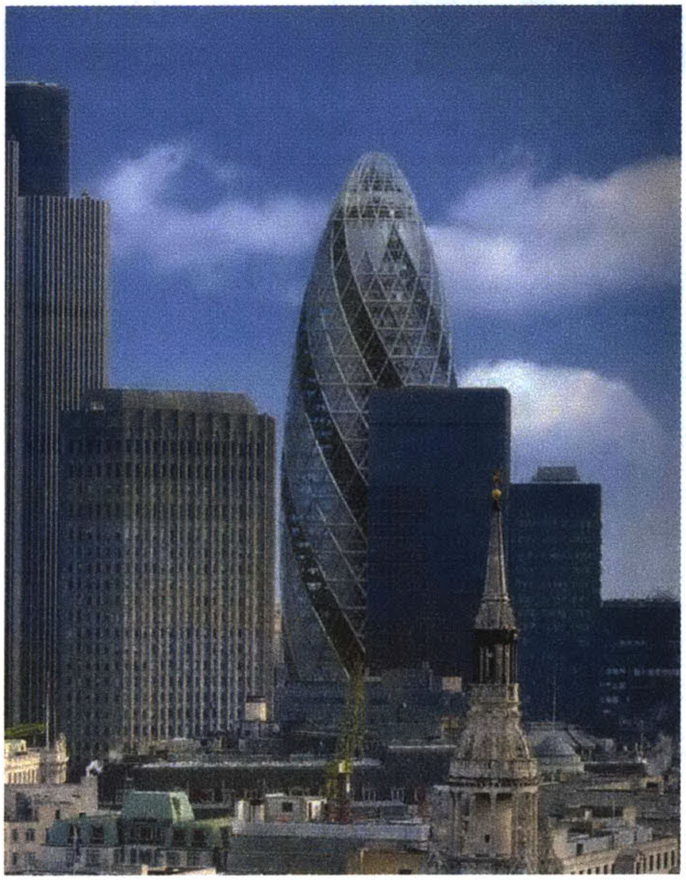


Figure 23: A rendering shows the spiraling atria concept. *(Source: Amelar, 2003)*

The design of the atria set constraints for the structure as well. "According to John Brazier, the project director at Arup, reconciling the 5-degree-per-floor rotation in the light wells generated the diagonal grid of the structure and the cladding."[xxxvii] This statement probably over-simplifies the description of the design conditions for the spiraling light wells, which also took into consideration solar access, views, and the structural diagrid.

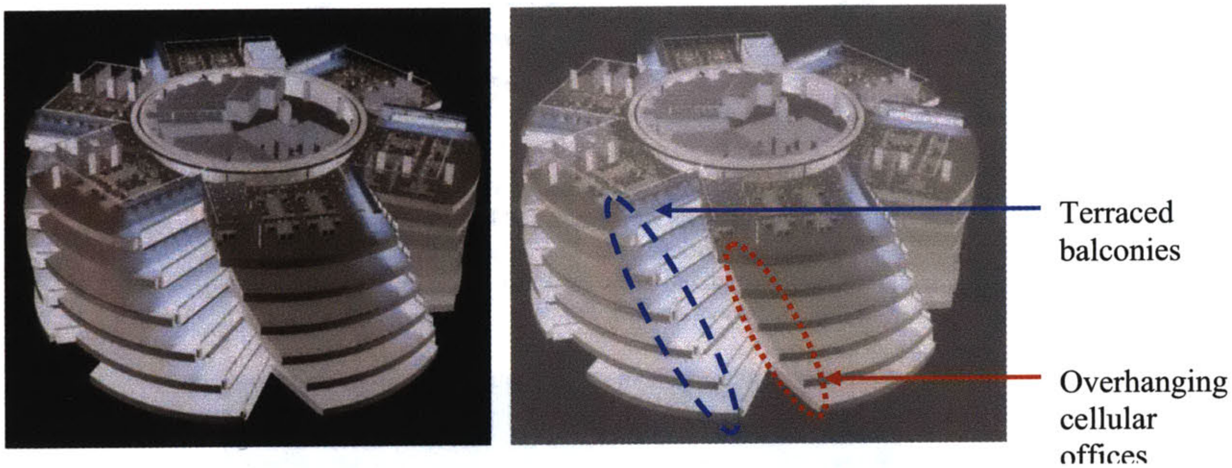


Figure 24: The 3-D model shows the rotated triangular voids that form the spiraling atria. The overhanging cellular offices and terraced balconies *(Source: Gregory, 2004)*

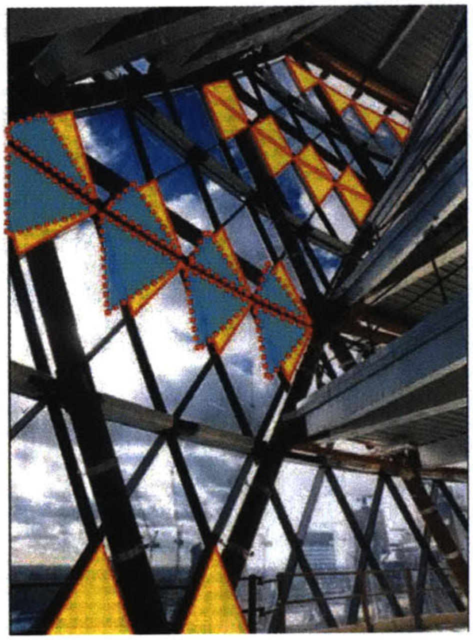


Figure 25: The photo is taken looking up in the "six-pack" atrium highlighting the BMS-controlled operable windows.
(Source: Hilson Moran)

Another significant influence in determining the effectiveness of the natural ventilation scheme is identifying how often the building does not require mechanical cooling. The mixed mode considerations were translated into a diagram showing the mode of operation based on the outdoor temperature. (see Figure 26). From this diagram, one may deduce that the natural ventilation potential is significant and should be pursued in design and second, that this breakdown serves as a basis for guiding the controls for the building management system.

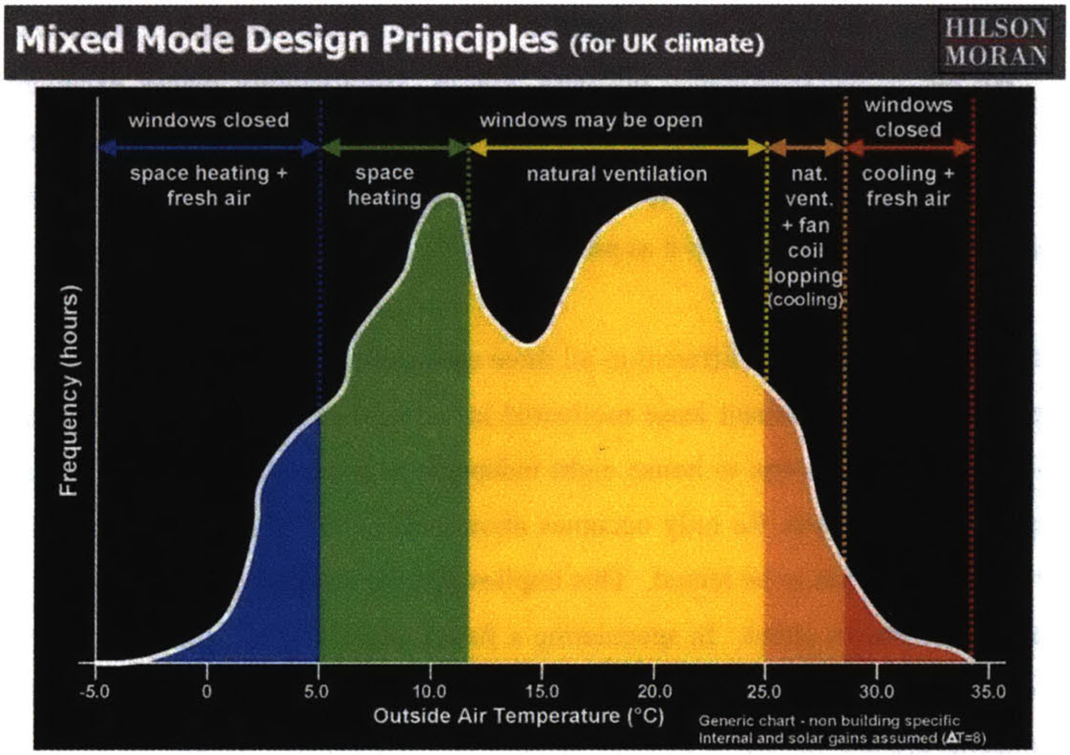


Figure 26: The "Mixed Mode Design Principles" diagram identifies what conditioning methods should be used and the number of hours they can be used based on the outdoor temperature. *(Source: Hilson Moran)*

4.2 Client influence & anticipating future tenants

Most discussions regarding clients and green design fall on two ends of the spectrum: either the client specifically requests and supports environmental goals, or the client is wary and reluctant to invest in green design. The client, Swiss Reinsurance company, represents the first description, and they sought out Foster and Partners because of their environmentally-conscious reputation; therefore the design team did not have to "sell" the green design to the client but were encouraged to push the environmental goals. The Swiss Reinsurance company recognizes that their responsible approach also has public relations benefits. As Sarah Fox, of Swiss Re says, "We wanted an environmentally responsible building. We didn't have a checklist; we asked Foster to explore what was possible. We are in the reinsurance business. For us, sustainability makes excellent business sense because we pay claims on behalf of clients for floods, heat waves, droughts. To the extent that these claims are related to global climate warming, it is only prudent of us to contribute as little to it as possible."[xxxviii]

The client/tenant relationship is different in all three case studies. The Genzyme building is developer built and long tenant lease motivated investment in the building. The San Francisco Federal building was to house eight independent government agencies, all of whom required input. Swiss Re only occupies about half of the 40-story building, the remainder of which has yet to be rented. This implies that the design team had to account for not only the unknown client. In speculating a future client's needs, the design team had to in effect "fool-proof" the building. Relative to the natural ventilation design, the primary concerns are that the client will take actions that will prevent the airflow through the space. How can the original design team make provisions so that this does not happen?

First, one may imagine a number of scenarios that would cause the blockage of airflow. For instance, if more acoustical privacy is needed next to the multi-story atria, the client may choose to put up a partition closing off the open balcony. To prevent this, the design team may warn against it in the operations and maintenance manual. Or, more effectively, the design team chose to mitigate acoustic annoyances by providing “invisible white-noise curtains [that] mysteriously absorb sound overspill between break-out spaces and workstations.”[xxxix] While the adjective “mysteriously” does not sound very convincing, the important thing to note is that the acoustic implications were taken into consideration. Another possibility for the ventilation design to be impaired is if the new tenant decides that the open plan office space would better be used as an enclosed conference area. To account for this, the fresh air inlet at the plenum has been over-designed by 50% to maintain adequate supply air in anticipation of changes in program. In addition, the different tenants may have different heating loads and cooling needs that vary from floor to floor. For example, if one company has a high density of people and heat-producing computers, or puts a server room on one floor, the cooling needs might be greater than on a neighboring floor. To address this need for varied cooling demands, local air handling units are located on every floor.

4.3 Simulation: The role of Hilson Moran

The simulation services they provided were essential to understanding the airflow, comfort conditions, and energy use of the building. The scope of Hilson Moran's involvement included "assisting with the development of early environmental concepts through to the full design of M & E systems, building management systems, fire protection and public health systems."[xl] Hilson Moran's natural ventilation objective used the pressure differentials across the atria façade (the six-story atria spans 30° of the circular plan) to drive the airflow. To understand this airflow, computational fluid dynamics (CFD) and dynamic thermal modeling (DTM) were used at different stages of the design process. In addition to determine airflow behavior in the atria, special attention was given to the restaurant space at the top of the building. In order to understand how simulation should be used in future designs, it is important to understand how, when, and why the Swiss Re building design team engaged in simulation.

Early in the design process, CFD was used to analyze the environmental conditions and determine if they were appropriate for a natural ventilation design. The early CFD results formed the basis for the team to adopt a "mixed-mode" design, atypical for the high-rise typology.[xli] At this stage, the CFD studies are done at an urban scale, to determine the pressure on the building. (see Figure 27)

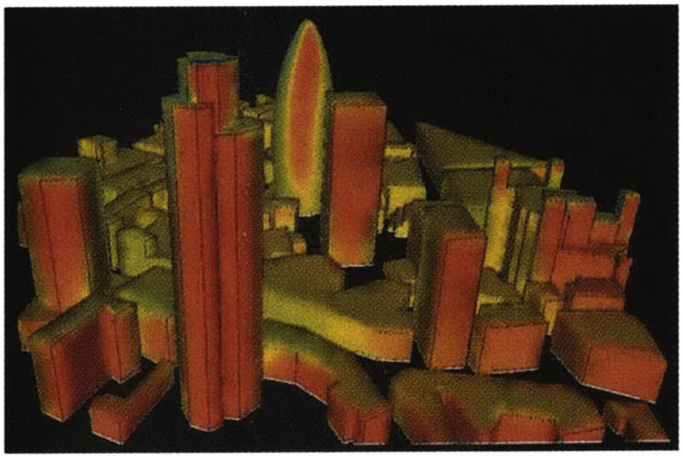


Figure 27: CFD simulation shows reduced wind pressure on the façade of Swiss Re building as compared to its rectilinear neighbors. *(Source: Williams.2002)*

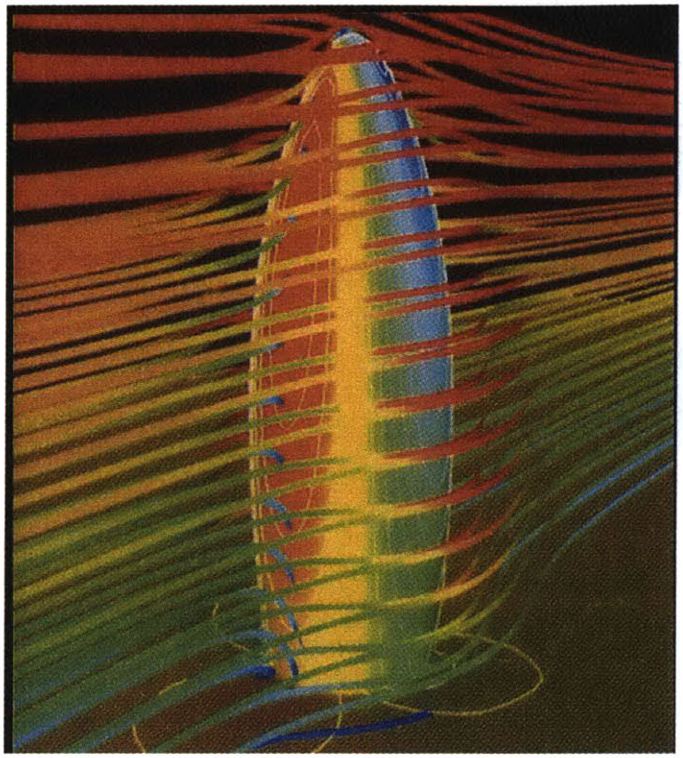


Figure 28: CFD simulation uses color gradients to show the wind velocities and direction as well as the pressure on the façade. *(Source: William 2002)*

The next design goal was to maximize the amount of time natural ventilation could be used in the building. "The CFD was used in conjunction with dynamic thermal modeling (DTM) initially to calculate the thermal performance of the building. The results were used as a basis to undertake further studies and a more detailed analysis of other aspects of the design, including the ventilated façade, the light wells, natural ventilation of the offices, entrance hall, and top of the building dome. CFD has also been used to measure the external conditions prevailing at the top of the building and interpolate these results over the rest of the building to assess natural ventilation potential."[xlii]

CFD was used to assess 14 different façade options. "CFD was used to examine design issues such as optimum ventilation rates, position of the blinds, and entry and exit points for the ventilation air … CFD was also used to examine the air flow on the office floors, and ventilation schemes for the lobby."[xliii]

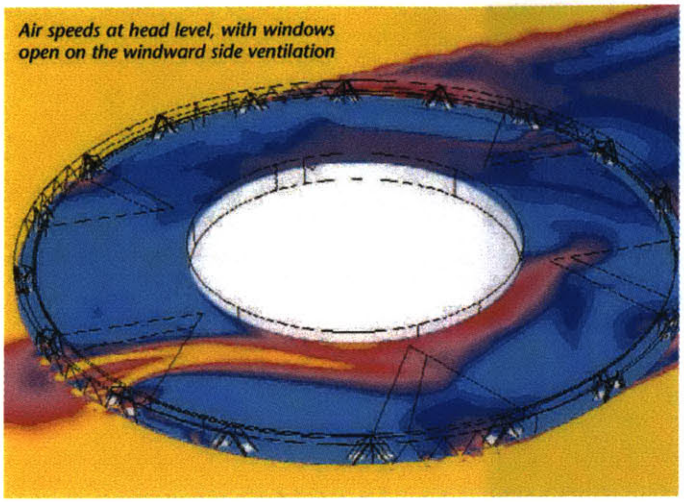


Figure 29: CFD showing "air speeds at head level, with windows open on the windward side ventilation." *(Source: Hilson Moran)*

Hilson Moran evaluated comfort conditions under the glass dome at the top of the building, resulting in recommendations for glazing and ventilation strategy. "In the final design, the ventilation [under the dome] is provided by a displacement system coupled with a chilled floor. CFD analysis was used to examine the thermal performance of the dome in both peak summer and winter periods, and the comfort of the diners and visitors in these areas was evaluated."[xliv]

"Energy consumption will be approximately 150kWh/m². This represents a savings of up to 50% when compared with a traditionally serviced commercial office building of similar type and size."[xlv] When considering such statements, it is important for the critical reviewer to understand what the Swiss Re building is being compared to in order to appreciate the significance. In this case, the information from the engineering team at Hilson Moran compares the Swiss Re to standards published by the Building Research Establishment.[5] The reputable resources are indicative of a valid, fair comparison. In addition, it is useful to future projects to understand how these predictions were made: the Dynamic Thermal Modeling was used to predict the energy consumption.

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[5] Benchmark Offices ref. DETR Econ 19

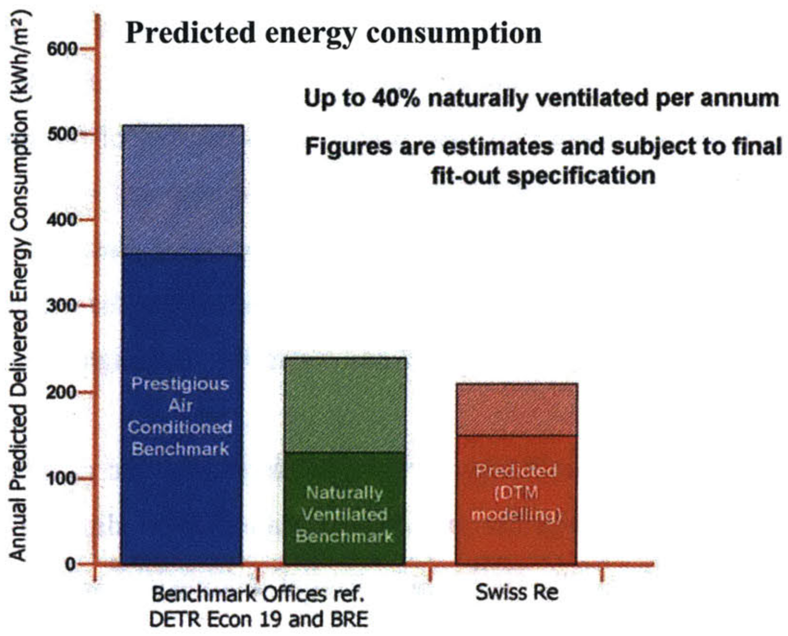


Figure 30: The predicted energy performance of the Swiss Re building. *(Source: Hilson Moran)*

4.3.1 Façade design: Ventilation and daylighting considerations

CFD was also used to evaluate 14 different façade designs. The final façade design of the facade at the office areas consists of a double-glazed outer skin with a ~1 to1.5-meter wide ventilated cavity containing perforated blinds for solar control. The ventilated cavity keeps the interior cool by exhausting the hot air in the façade. There are two types of glass panels on the façade: a diamond-shaped panel that stretches from floor to ceiling, and a triangular panel that fills the gaps between the diamonds and is half as tall.

There are two types of openings to outside air: the first is the operable windows on the atria and the second is an inconspicuous slot at the plenum. The atria have a single-skin with dark-colored high performance solar control glass. A slot for air intake is located where the two triangular-shaped panels meet at the floor plenum. "Around the perimeter of each floor is an air plenum, opening to external air through a louver blade at the horizontal glazing joints. This plenum is over-designed by 50 per cent in case future uses for the building (additional conference room partitioning, for example), demand additional ventilation."[xlvi]

The façade design is the crucial environmental-control component in the Swiss Re building and required a concentration of design effort. The Swiss Re building's façade is more complex in construction than the other two case studies for a number of reasons. The façade's height and structural capacity dictated the diagrid patterning and sizing of large structural members that required a large (1+ meter) cavity between glass panes. (see Figure 31)The inclusion of a ventilated cavity and an exterior air inlet at the plenum were also non-standard features that had to be worked out and tested by the design team.

The façade design was facilitated by the familiarity between the architects and cladding (Schmidlin) contractors who had worked together previously on another building. The two parties collaborated on London's Clay Hall using similar parametric modeling techniques.

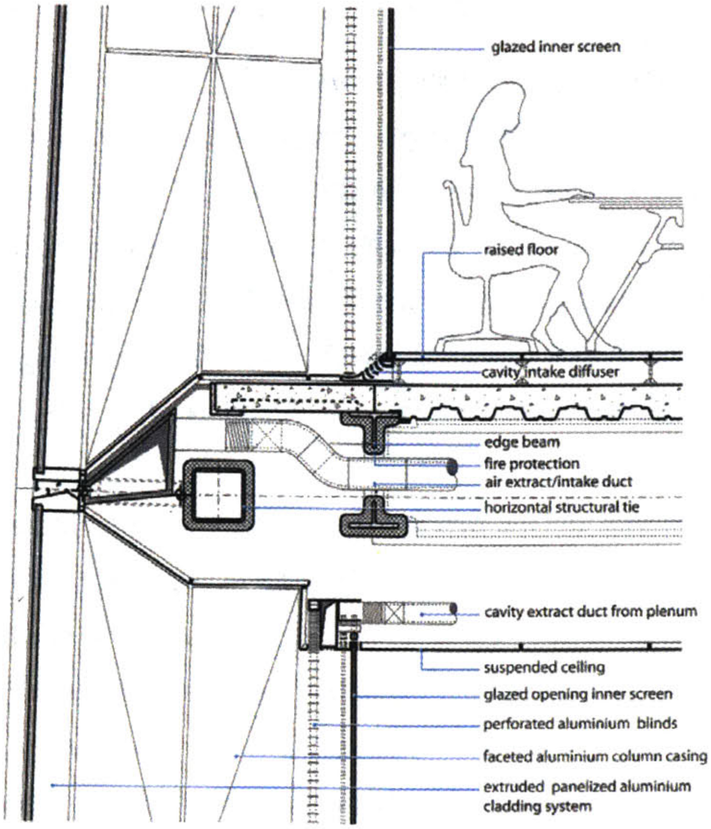


Figure 31: Section showing ventilated façade and air intake at the plenum. *(Source: Amelar)*

4.4 Post occupancy evaluation

While data regarding the post-occupancy has not been processed for public use, conversations with engineer Matt Kitson of Hilson Moran indicated that they have begun gathering data monitoring the building. The data collected that is relevant to the natural ventilation performance includes energy consumption as well as the number of hours the windows are open (indicating no need for mechanical cooling). Hilson Moran's engineer Ben Abel describes his own observations when during the commissioning process:

> *"During this process when they were testing the window opening mechanisms I visited the site and took some measurements with an anemometer noting speed and direction. The data correlated very well with the predicted results. The monitoring process is logged by the building management system which compares information from the external weather station to the internal conditions and opens the appropriate windows. The controls include a learning loop so as the building gets to 'know' how the building reacts it should be able to predict what it needs to do to maximize the natural ventilation periods." - Ben Abel, Hilson Moran*

When discussing the accuracy of the energy use predictions with Rob Harrison of Foster and Partners, he indicated that the firm had reasonable confidence in the predictions because of experience with a past project, the Commerzbank building, where they not only met but exceeded the energy savings projections.

Figure 32: Swiss Re building natural ventilation design diagram (following pages) *(Small image sources: Hilson Moran, Foster & Partners)*

Project Timeline: Swiss Re building

1998
Foster & Partners commissioned after Swiss Re acquired the site in 1997

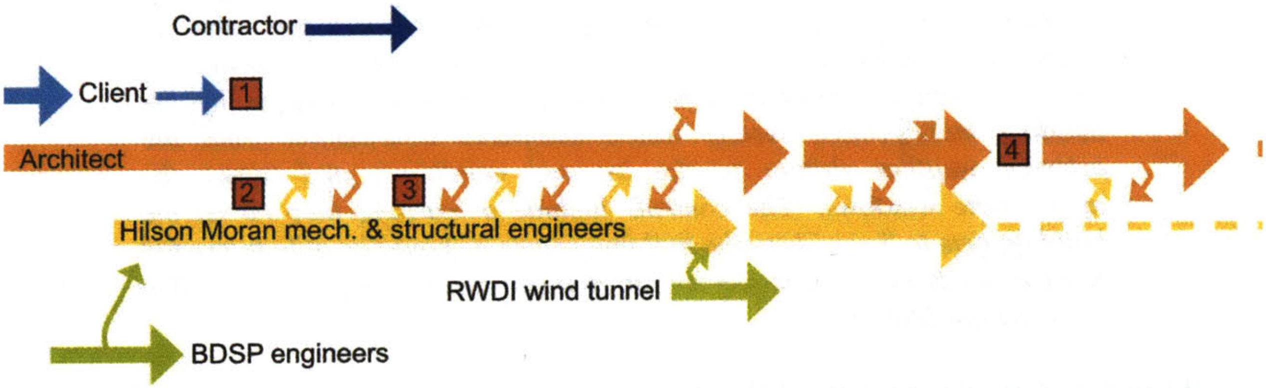
1999
Scheme submitted for planning permission

2000
July: planning permission granted

2001
Jan.: construction began

Oct: steel ceremony

Information flow influencing natural ventilation design



Contractor

Client 1

Architect

4

2 3

Hilson Moran mech. & structural engineers

RWDI wind tunnel

BDSP engineers

Swiss Re reinsurance recognizes environmental concern as a business interest 1

Collaboration to define clear objectives + confirm feasibility 2

Simulation to evaluate comfort, energy use, and airflow 3

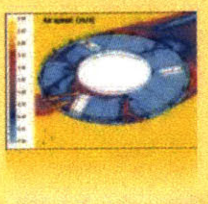
Familiarity with cladding contractors, and experience with Commerzbank 4

quick exterior CFD studies to get wind pressure values on facade, later validated by wind tunnel test

Dynamic Thermal Modeling showing energy usage

CFD testing of interior air speeds and temperatures across one floor

CFD testing of six-story atria's air speeds and temperatures



2002

April: cladding installation

Nov.: topping out of steel frame

2003

Oct.: base building, shell, & core complete

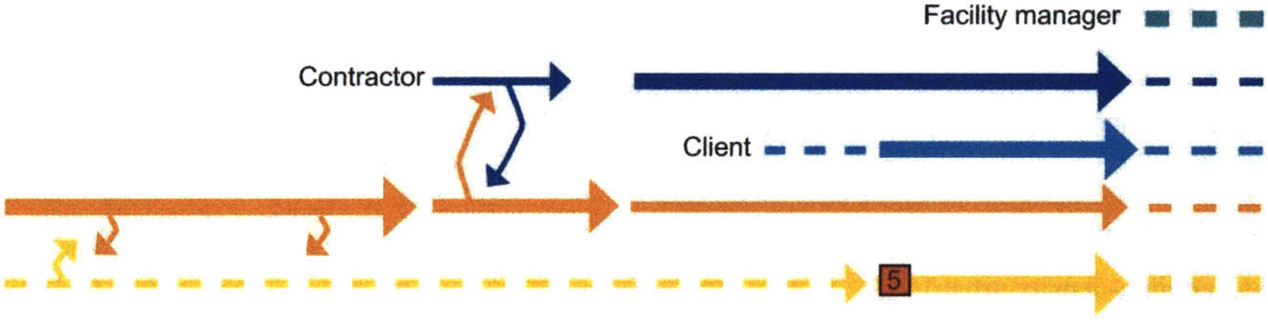
2004

April: opening

June: top of building complete

2005

Monitoring by Hilson Moran



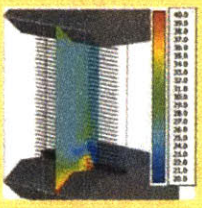
🟥 = critical moments

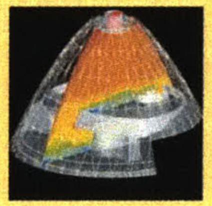
Swiss Re hires Hilson Moran to monitor building (separate contract). 5

CFD testing of facade options

CFD testing of top of building

fine-tuning + controls system “learning”





5. Genzyme Building

Genzyme building quick facts:

Architect: Behnisch, Behnisch & Partner

Client(s): developer: Lyme Properties, tenant: Genzyme Company (30 year lease)

Collaborators: Buro Happold, structural and MEP engineer; House and Robertson, base building associate architect; Next Phase Studio, tenant fit-out associate architect; Bartenbach LichtLabor, Austrian lighting consultant; Turner Construction, general contractor; Genzyme engineers, facility managers.

Location: Cambridge, Massachusetts, USA (mid-rise, medium-density urban)

Major materials: concrete frame, glass facade

Total floor area: ~314,000 sq. ft..

Natural ventilation strategy: The 12-story mixed-mode building utilizes the stack effect: air is drawn in through operable windows on the perimeter, rises and exhausts in the central 12-story atrium.

Figure 35: Genzyme building *(Source: Behnisch)*

5.1 Establishing design objectives

The design of the Genzyme building began as a collaboration between architect and engineer for a competition-winning scheme approaching the office design from the inside-out. Focusing on the quality of the office environment for the employees, Stephan Behnisch, of Behnisch, Behnisch & Partner and Tony McLaughlin of Buro Happold incorporated social and environmental goals into the proposal. The fact that the two senior designers were familiar with each other's working styles from previous projects facilitated the teamwork. The project has many laudable environmentally-responsible aspects, including an advanced daylighting system, but the description of design objectives here will focus on the features influencing the natural ventilation design. It is important to recognize that compared to the other two case studies, the Boston climate is less favorable for natural ventilation because of its harsh winters and hot muggy summers. For this reason, the building design intent was to create a mixed-mode building that could utilize natural ventilation for energy savings and operable windows for occupant satisfaction when appropriate. Unlike the San Francisco Federal building, the availability of a backup mechanical system determined that the natural ventilation parameters were not the number one priority in design.

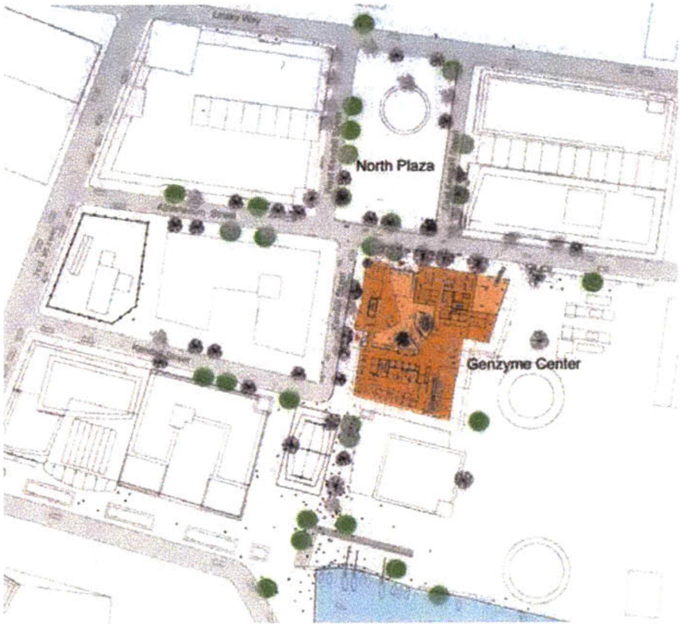


Figure 36: Site plan shows surrounding office developments.
(Source: Behnisch)

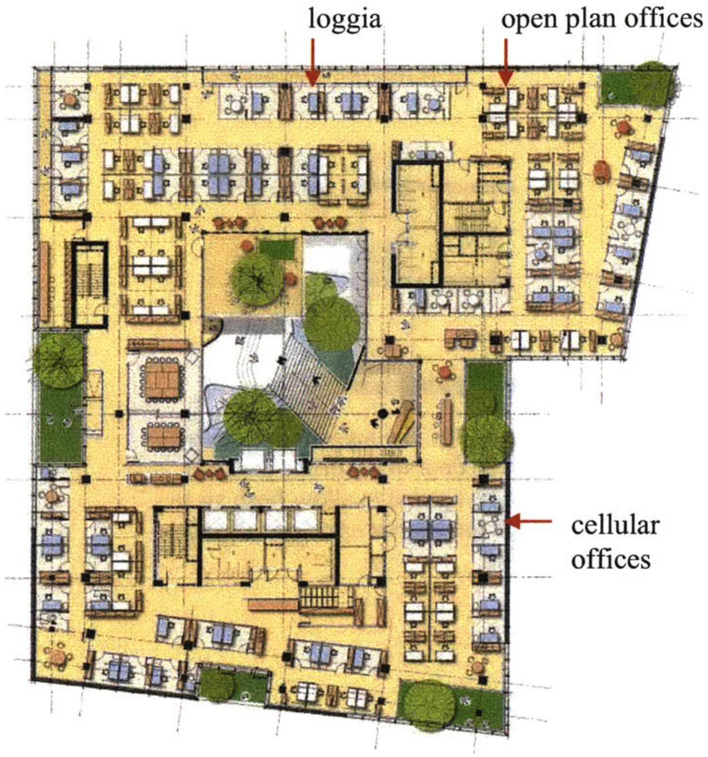


Figure 37: Schematic floor plan shows cellular vs. open plan *(Behnisch)*

The width and depth of the site made an atrium building a logical choice, particularly to provide light into the building core. The basic scheme for the natural ventilation can be best summarized by three diagrams showing how the building opens to the outside during milder fall and spring the conditions and shuts out the extreme summer and winter conditions. The concrete structure provides thermal mass for night cooling during summer. In addition to the atrium, some parts of the building use an atypical inhabitable 4 foot-wide "loggia" space to buffer the external temperatures that functions like a double-skin façade. (see Figure 37) The lower, manually-operated windows and the upper automated windows can have three configurations: [1] all windows and doors to the office are open allowing air to reach the office in spring and fall (see Figure 38 & Figure 39); [2] windows are open but the loggia is sealed off from the offices to ventilate itself in summer (see Figure 40 & Figure 41); [3] windows are closed to create a warm insulating space in winter (see Figure 42 & Figure 43). In addition, there are user-operated windows in the façade areas without the loggia.

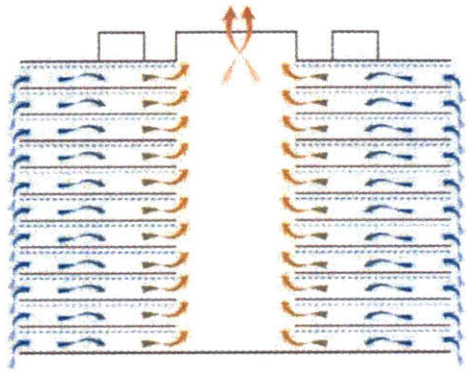


Figure 38: Diagrammatic section shows airflow for passive cooling during summer mornings, spring, and fall. Air enters through perimeter windows and exhausts via stack effect in the atrium. *(Buro Happold)*

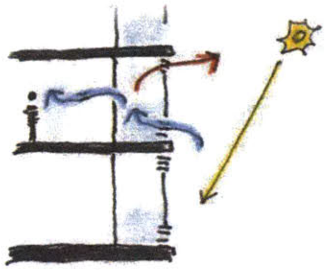


Figure 39: The loggia's windows and the door to the office area can both be opened to allow fresh air to reach the interior space in fall and spring.

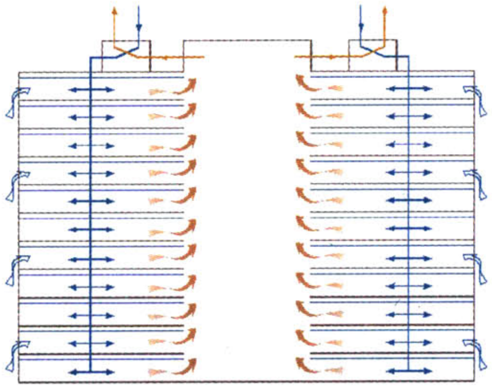


Figure 41: Diagrammatic section shows airflow for mechanical cooling and exhaust fans at the top of the atrium for summer months. Windows can be opened to suit the user's preference. *(Buro Happold)*

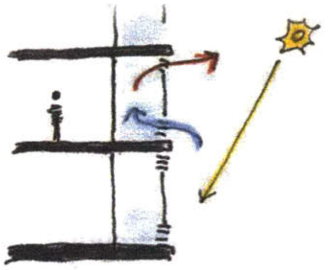


Figure 40: The loggia's low and high openings allow air to ventilate the cavity to cool it in summer.

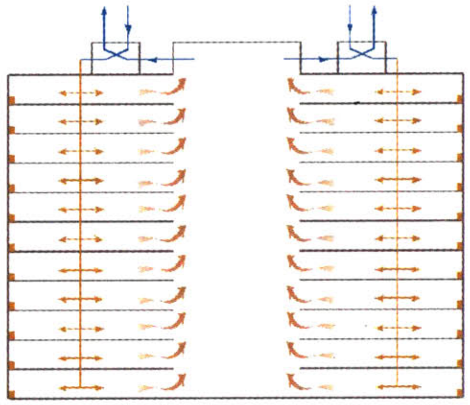


Figure 43: Diagrammatic section shows heating system during winter. Windows remain closed. *(Buro Happold)*

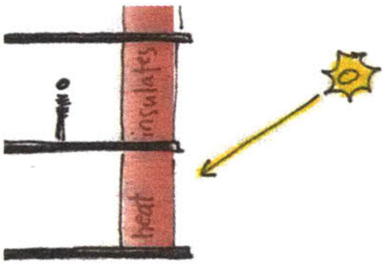


Figure 42: The loggia's openings are closed in winter so it acts as an insulating space.

Unlike the other two case studies, the design of the Genzyme building did not include computer simulation to test the airflow or thermal comfort conditions. Engineer Byron Stigge explains that Buro Happold and Behnisch had both independently done analysis work on single-story, externally ventilated double skin facades recently. In addition, the fees for the project did not account for simulation work and the engineers did not feel it was appropriate to ask for additional fees, particularly because they had just done some analysis on similar assemblies. It can also be speculated that because the mechanical ventilation is available, the comfort conditions or air velocities do not need to be verified or quantified. It was probably sufficient to know that the option of natural ventilation was available if desired. The choice to forgo simulation was influenced by reliance on the design team's recent experience with similar systems, the lack of funding, and existence of the back up mechanical system.

5.1.1 Designing the details

Similar to the San Francisco Federal building, the designers were challenged with placing the cellular versus open-plan offices at the perimeter. Unlike the central enclosed cabins in the SF Federal building, there are no strict rules regarding placement of cellular offices or conference rooms in the Genzyme plan. The issues under evaluation included employment hierarchy, transparency for daylighting, enclosure for visual and acoustic privacy, and physical blockage of ventilation. While each floor plan varies, the perimeter of the building consists of many types of spaces: cellular offices, lounge gardens, open plan offices, and a unique 4-foot wide inhabitable loggia. How did the designers resolve each of these conditions to work with the natural ventilation design? Particularly in the case of the cellular offices, how does air travel from the façade to the atrium? Each floor has a combination of cellular and open plan offices on the perimeter, each of which is climatically independent. In other words, it is assumed that people working in the open plan office area will coordinate their choice to open windows or use mechanical cooling. The cellular offices have a more sophisticated system that senses when a window or door is open and consequently turns off the mechanical cooling to that office (the damper between the local air handling unit and the office is closed or opened in response to the sensor's input). This system is highly applicable to prevent wasting energy in future mixed mode buildings with enclosed program spaces. This is especially useful in a system with chilled ceilings where the warmer, more humid air entering through an open window might cause condensation on the cool ceiling.

5.2 Client influence

Fortunately for the design team, the client's goals aligned with the architectural aspirations, and instead of requiring convincing, the client was driving the sustainable and social goals. Genzyme's Dutch CEO Henri Termeer played an influential role in the building design.

The Genzyme building is different from to the other two case studies because the design team worked with two types of clients, the developer and the tenant. Typically, natural ventilation and other energy-saving features of the design are not appealing to a developer because they often involve higher first costs, and the financial savings and occupant satisfaction will not be benefit by the developer. This often deters developers from investing time or funding to sustainable design. In order to address future developer projects, it is helpful to understand what kind of agreement developer and tenant established and how they divided the financial responsibility.

In this case, the developer paid for the core and shell of the building, and the tenant, Genzyme, funded the internal fit-out. The negotiation and understanding between the developer and tenant is crucial because from the developer's point of view, the atrium area is usually seen as area that cannot be rented and is therefore wasteful. On the other hand, the socially-concerned tenant recognized the atrium's value to the quality of the office environment.

The natural ventilation design was highly dependent on the tenant situation. Without one secure tenant, issues of privacy, security, and leasing probably would have prevented the full-height atrium design. The fact that the tenant, Genzyme, had a long-term lease and knew it would occupy the building for at least 30 years meant that it were able to support design ideas that would have been impossible in a typical developer/tenant relationship.

For example, the atrium, which is central to the natural ventilation design, also serves social functions, providing stairwells and common areas to build connections between floors. If the floors required segregation because of multiple tenants, the function and allure of the atrium would change. Another consideration with multiple tenants is acoustical privacy. While currently the white noise from the ground-level fountain provides a comfortable acoustic environment, one might imagine the potential difficulties of tenants with different needs: if one young firm likes to play the radio, and another requires private discussions, and takes coffee breaks at social area adjacent to the atrium, problems may arise. In addition, without a secured tenant, the developer probably would hesitate to support the forward-thinking design because of fear that the sustainable approaches might not appeal to renters. Without Genzyme's long-term lease, the developer probably would have perceived features like the natural ventilation a risky investment that may not appeal to mainstream renters.

5.2.1 Navigating the value engineering process and construction

The tradeoffs and conditions surrounding the value engineering process are impossible to narrate as a coherent sequence of events as there are countless influences and variables at work. The major component affecting the ventilation that was not included from the original design scheme was the raised floor system. In order to better understand the applicability of such systems to future projects, the factors influencing the choices in the Genzyme building are discussed here. The raised floor system had a few implications including the ability to provide a displacement ventilation system and run electrical and information services underneath the floor. The alternative to this system is to use a drop-ceiling to conceal the ventilation and electrical services. The drawback to using the drop ceiling is that it covers the once exposed concrete ceiling which loses heat by convection to the air during the night to effectively provide cooling the next day. The difficulties in constructing the raised floor system included unfamiliarity and complicated coordination. Although common in Europe, many American construction companies are unfamiliar with raised floor designs and prefer to depend on "tried and true" construction methodologies. While this reaction is sensible in terms of potential increased cost, liability, or time, the hesitance to integrating new construction techniques makes it difficult to gain experience in building new systems and suspends innovation. There is a gap between the systems that are optimal in theory and the contractor's level of comfort executing such proposals. Perhaps large construction firms such as Turner Construction Company would benefit from incorporating education of new construction techniques into the company policy. It should be recognized that Turner Construction Co. did take on many aspects atypical to American construction, including the advanced daylighting system, double façade, roof gardens, and more. Turner Construction Co. also has taken an active role promoting its green image and initiating market research about perception and cost of green design. Given that the company clearly understands the value of green design, how could the coordination of resources be improved to facilitate aspects like the raised floor in future projects? One possible solution would be that the product manufacturer volunteers to provide on-site assistance implementing its product.

5.3 Post occupancy evaluation

Of the three case study buildings, the Genzyme building has been in operation for the longest amount of time, currently under evaluation for two winters and one summer. The Genzyme building is interesting because the facility manager / mechanical engineer is administering the post-occupancy evaluation without any additional contract to include members of the design team. The Genzyme company has its own mechanical engineers that manage its facilities (at multiple locations). These engineers are more knowledgeable than a typical building manager and are responsible for monitoring the mechanical systems and addressing occupant complaints. During the background research interviews in London, one professional stated that some building managers prefer to have a "quiet life" implying that they are not interested in tracking the building's performance and making appropriate responses. This is not the case for Genzyme, where active engineers review and respond to the continuous flow of data from the building management system (BMS). Large naturally ventilated buildings can be expected to have a period of time where monitoring is crucial to fine-tuning the systems, requiring an active team of engineers.

5.3.1 Post occupancy evaluation: Detection of and response to problems

A common difficulty with BMS data is lack of time necessary to sort through it. Genzyme's own engineers along with occasional assistance from Buro Happold's (the design team) engineers have responded to a number of issues during occupation. The primary issue affecting ventilation in the Genzyme building is excessive infiltration from the façade, particularly in the winter months. The stack effect in the atrium produces desirable air flow in the building when temperatures are moderate and the open windows can provide intake air or the temperature difference between outside and inside is extreme. During winter, the large difference between cold outside and warm inside temperatures results in a too strong stack effect in the atrium. With great amounts of air exhausting out the top, the negative pressure at the ground floor draws in enormous amounts of air through leaks in the caulking. This is problematic because it causes drafty conditions and occupant discomfort, as well as admitting unanticipated amounts of cold, dry winter air necessitating excessive heating energy. Actions were taken by the engineers to measure the air infiltration at the façade using a vane anemometer and thermal imaging. (see Figure 44) In response to these tests, efforts were made to repair the leaks in the caulking in the façade.

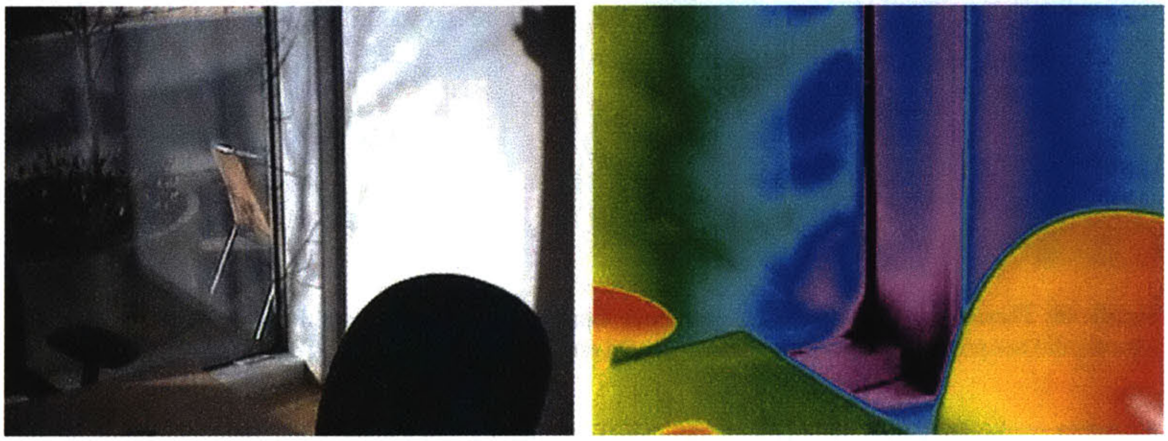


Figure 44 Thermal imaging at the façade shows the infiltration of cold air due to leaky caulking. *(Source: Buro Happold)*

In some cases, mechanical breakdowns are the root of problems that adversely affect the ventilation of the building. The thermal imaging is also used to detect mechanical breakdowns of façade components. In the Genzyme building, thermal imaging detected instances where the motorized windows, which are automatically controlled by the BMS, were not closing properly and causing drafty conditions. (see Figure 45) Because large naturally ventilated buildings often utilize multiple moving parts, there is an increased possibility of components malfunctioning and their maintenance should be anticipated as a routine responsibility of the facility manager. One of the reasons for mechanical difficulties is an inadequate façade assembly. Because many façade systems are custom designed for large naturally ventilated buildings, they are basically big, innovative experiments. It can be expected that more robust operable façade systems will become available as the market for such products continues to grow. In the meantime, a knowledgeable facility manager should be able to spot inconsistencies in the BMS data and respond appropriately.

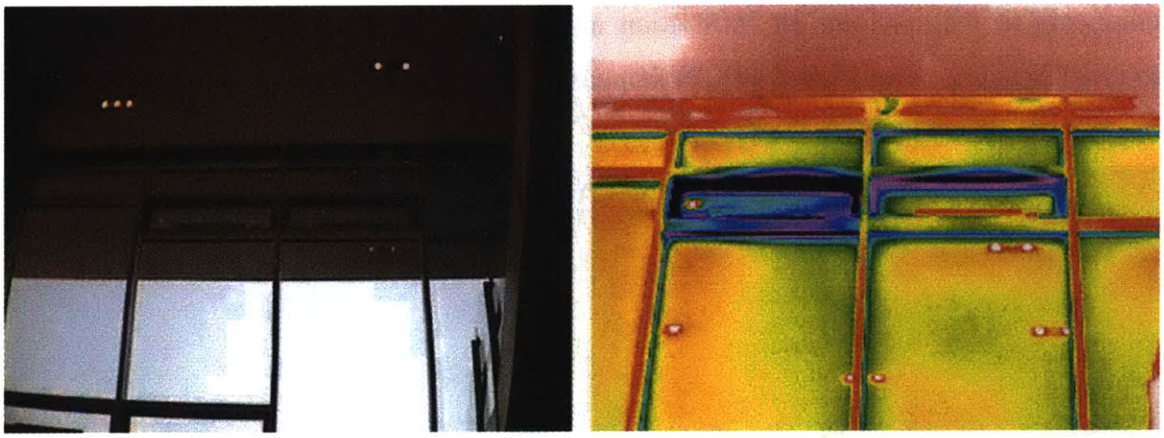


Figure 45: Thermal imaging of the façade reveals a mechanical failure where the BMS-controlled window actuator did not properly close the window and cold air is entering the space. *(Source: Buro Happold)*

Another issue affecting air infiltration is the design of the lower, user-operated vent in the loggia space. The lack of a sufficient seal results in air entering the loggia through the gap between the metal covering and the metal frame. (see Figure 46 & Figure 47) The permeation of cold air during winter undermines the function of the loggia as an insulating buffer space. This leakage is a personal observation, and to my knowledge, was not specifically addressed by the facility managers. Perhaps it is of low priority because the leakage occurs in an un-occupied zone, the loggia, therefore only results in sub-optimal building performance but is not a source of occupant dissatisfaction. In future projects, particularly those in cold climates, designers should take care to detail openings in the façade accounting for the air tightness of the building to avoid energy waste and occupant discomfort. In the façade specification, the pressure and temperature differences should be accounted for in denoting the quality of the façade components.

Figure 46: The vents could be better sealed with a rubber strip to prevent infiltration of cold air in winter.

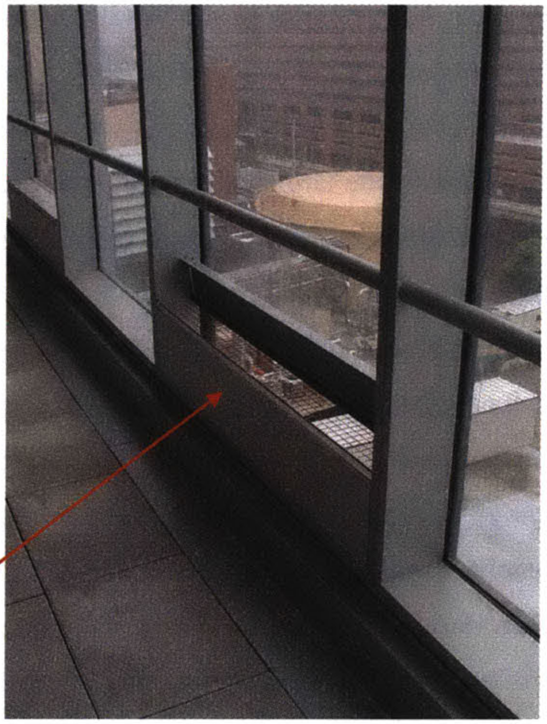


Figure 47: The inhabitable loggia space contains lower user-operated vents.

5.3.2 Post occupancy evaluation: Promoting its importance

The issue of post-occupancy evaluation is often dependent on the assignment of funding and responsibility for monitoring and improving building performance. As discussed in Chapter 2, monitoring in a large naturally ventilated building is necessary for a number of reasons. In the case of the Genzyme building, the mechanical engineer on the design team was not contracted to continue monitoring the building's performance. In this case, the client had its own infrastructure of building managers and mechanical engineers, it seemed redundant to hire the design engineers, Buro Happold, for the monitoring. Buro Happold was called in to help with problems like the infiltration and thermal imaging, and would be interested in following-up on the building's performance, but is hindered by the lack of funds. In addition, there is an interest from the design community to understand how the projected energy savings and predicted performance are functioning in reality. Byron Stigge of Buro Happold explains that the engineering team has been asked to publish papers on the operation of the Genzyme building but the lack of funding prevents the work from being done. The solution to this problem may have multiple options. First, similar to the PROBE studies in the UK, the government may recognize the potential and necessity of not only creating grants to help energy efficient projects get built, but also to provide a basis for design teams to follow up and share what they learned with the larger design community. In other words, government support for the design and later optimization of innovative green projects would be one way to facilitate the post-occupancy evaluations. Second, the client's recognition of the importance of monitoring would facilitate the setup of contracts to fine-tune the building. The allocation of funding for monitoring may be seen as unnecessary from the client's point of view, so research and publication in this area should focus on how monitoring would increase the energy savings and occupant satisfaction. By concentrating on promoting the client benefit, monitoring and optimization might become more common. For example, in Buro Happold's had a contract to monitor and optimize another one of their projects, the Wessex Water Operations Center in Bath, UK, for three years after completion of construction. One might think that building managers already fulfill this role. Hiring the design engineers is advantageous as compared to a facility manager because they understand the intent of the ventilation scheme and could therefore potentially respond more quickly and effectively. In addition, the design engineers could write about the building performance as compared to predicted performance for their own education and for the betterment of the design community at large. As Bill Gething of Feilden Clegg Architects, and RIBA Sustainability Advisor frankly said, "If you don't know whether the things you're specifying work in practice, it's hopeless." Future projects would benefit from understanding how ground-breaking projects like the Genzyme building have designed and optimized their natural ventilation systems and allocation of funding for monitoring would facilitate this. Future designers could reference documentation on buildings such as Genzyme to support design decisions and persuade clients.

5.3.3 Post occupancy evaluation: Managing Data

During the informational interviews in London (see Chapter 2), Greg Smith, Mechanical Engineer at Max Fordham commented, "If you've got a BMS, you get performance data practically for free. The problem is accessing all that data because you've got such a mass of it." In Genzyme's case, the BMS monitors all kinds of data; in fact, there is so much data, that it takes a trained eye to understand what should be recognized as abnormal. The BMS company is Andover Controls, and the system includes over 25,000 set points. Genzyme's own engineers are responsible for gathering and processing that data. Information about energy use, steam use, fan coil unit operation, damper positions, window positions, temperatures, and many more variables in the building are reported through the BMS. How does one sift through the information? In the case of the Genzyme building, the engineers look at daily data as well as plot trend logs that graph the desired data over a period of time. This was useful in fine-tuning items such as the fan coils. A separate company, Source One, tracks the utilities usage on the building. Their role was to report to the facilities managers how the building was performing, which was influential because it highlighted problems with the steam valves and metering, which were then corrected. This useful report was done in early 2004, after the building had been in operation for about half a year. Since then, there have been no glaring problems and therefore have not been subsequent reviews of energy usage, although they would be available upon request. In any situation, the more parties involved, the more complex the organizational responsibilities become. The operation of the Genzyme building now includes daily monitoring by Genzyme's own engineers, occasional consulting from Buro Happold, BMS coordination by Andover controls, and utility usage tracking by Source One. Because the large naturally ventilated building typology is relatively uncommon in the U.S., there is no protocol for how these parties should interact. This would explain why a more recent evaluation of the utility use has not been done in the Genzyme building: there is no explicit regimen to follow. On one hand the lack of a prescribed schedule can be seen as advantageous because the parties are free to respond as they deem necessary. On the other hand, it makes it difficult for facility managers or other responsible parties embarking on such a project to anticipate the necessary coordination. Having a regular routine of evaluation milestones would be helpful to facility managers. In addition, verifying targeted energy use goals would be beneficial for public relations and gratifying to the designers.

5.3.4 Post occupancy evaluation: Communicating with users

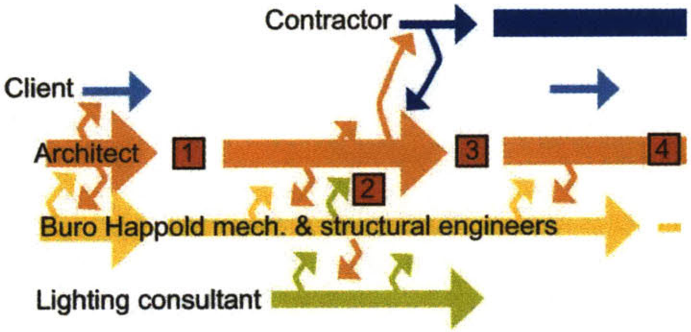
Discussion with the Genzyme engineers and facilities managers developed interesting conversation about communicating with occupants regarding feedback on their comfort and operation of the building. While there is currently no official way to get regular feedback from occupants, there are methods to communicate to occupants how to use the building. For example, when it is very hot and humid outside, the facilities manager will send an email alerting people not to open their windows. In addition, there is a monthly internet letter sent to employees regarding building updates. In a surprising approach, the facilities personnel have consciously decided to let people 'learn' about their building through trial and error. For example, if an occupant leaves a window open, facility managers purposely do not close it so that the person notices and simply remembers to close it the next time. Perhaps this is a more effective approach than attempting to prescribe anything non-intuitive or "teach" people about the building. Other large naturally-ventilated buildings have examples of communicating to users how to operate the building during certain conditions. For example, in Foster and Partners' Commerzbank, colored lights adjacent to the windows alert users whether or not they should open their windows. The lesson the designer should learn from this is to make the building operation as intuitive and robust as possible and to require the least amount of communication to the users.

Figure 48: Genzyme building natural ventilation design diagram (following pages)
(Image sources Behnisch & Behnisch, Buro Happold)

Project Timeline: Genzyme building

1998	1999	2000	2001
		May: Competition won Dec: Schematic design complete	April: Design Development complete April,May: Major value engineering exercise June: Foundation CD & Groundbreaking July-Oct: Phased structural CD Oct: Arch & MEP CD

Information flow influencing natural ventilation design

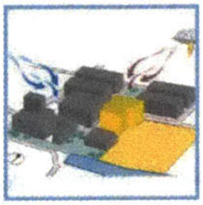


Genzyme CEO pushes environmental and social agendas 1

engineer and architect working together at competition phase

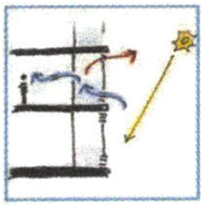
Collaboration to define clear objectives + confirm feasbility 1

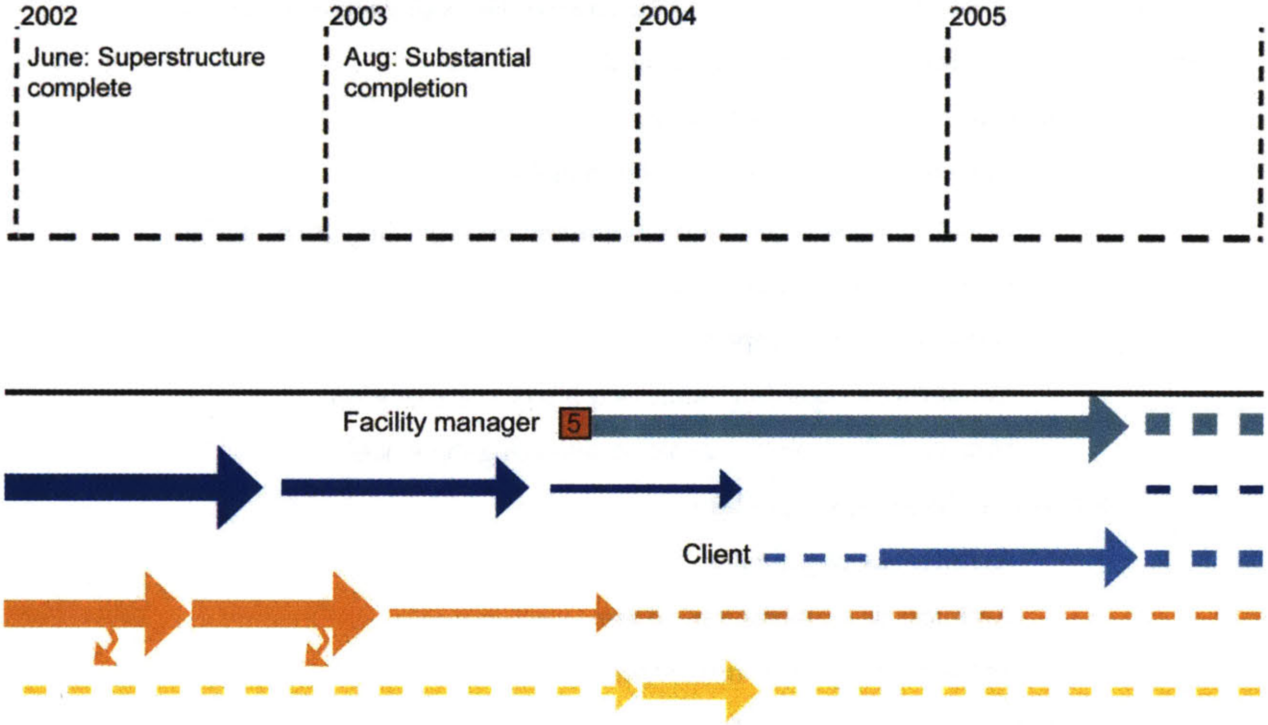
Climate analysis defines atrium scheme, daylighting, + operable windows



No budget for simulation 2

Design team relies on recent experience on similar double skin facades.

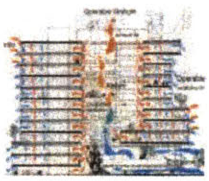




🟥 = critical moments

Value engineering negotiations 3

omit raised floor, add drop ceiling = decrease thermal mass



Construction starts while building is still under design 4

Increased difficulty in architect's coordination duties

Genzyme's engineers manage building + BMS data 5

Air Infiltration in winter: Buro Happold assists in thermal imaging.

6. Applicability to future projects

In order to apply the lessons learned from the case studies and interviews to future projects, the following topics will be addressed:

- 6.1 Structuring the project differently
  - Collaboration with research institutions
  - Anticipating additional time requirements regarding green design
  - Exploring funding options
  - Garnering client support
  - Conclusions regarding interdisciplinary collaboration
  - Sharing information to avoid re-inventing the wheel
- 6.2 New architect responsibilities
  - Architect as coordinator
  - Architect as simulation mediator
  - Architect as systems researcher
- 6.3 The future of simulation tools
- 6.4 The future of post occupancy evaluation

6. 1 Structuring the Project Differently

The architect is continually faced with the challenge of comparing options in building design and operation based on multiple factors. Attempting to select the "best" choice that satisfies the design goal, is economical for the firm, and respects the time constraints of the project is a complex task. Gathering information to assess the options is the first step. When making decisions affecting environmentally-responsible design, this information-gathering phase can be time-consuming and therefore costly for the firm. Oftentimes it is more efficient for the firm to adhere to familiar (tried and true) methods of working, which may or may not fulfill the sustainable goals.

The literature review, industry interviews, and building case studies reveal how the methodology of producing a large naturally ventilated building differs from the current methodology of creating a typical mechanically ventilated building. The typical building may appear more profitable to an architecture firm because its familiarity with the process expedites the production and presumably increases its profit. Yet, the desire to integrate sustainable principles in design means changing that baseline process. The architect requires understanding of these changes as options in the process and must be aware of them in order to achieve the goal.

The owner-occupied SF Federal building demonstrates principles of integrated design and non-standard collaboration that could be applied to other future projects. From this case study one gains a more critical understanding of the pros and cons of working with a research institution, of exploring funding options, of garnering client support, and of the architect's role as a coordinator.

The developer-built Genzyme building's approach, including the environmentally-conscious tenant involvement in the design process, can be applied to future projects. The Genzyme building can be referred to as a demonstration of the designer's role in negotiating the incorporation of technologies (daylighting system) and design features (inhabitable double facade) uncommon to the US without the use of building simulation tools. In addition, the Genzyme engineers are managing and monitoring the building and have shared available information on the post-occupancy evaluation.

The owner-(partially)-occupied Swiss Re building is significantly taller than the other two case studies and is an example of professional collaboration for intense building simulation work.

6.1.1 Collaboration with research institutions

The SF Federal building design team's collaboration with a research institution is unique in comparison to the other two case studies examined in this thesis. Other instances of architects collaborating with research institutions are evident in daylighting research, but rare or non-existent in ventilation research. In fact, the SF Federal building is the first project LBNL has working on in this design capacity. This is only logical since LBNL's primary focus is research and their emphasis is not contracting or building delivery.

Being that this research collaboration was the first of its kind for LBNL, it raises the question, "Why did Morphosis decide to pursue the unprecedented collaboration with a research institution instead of hiring a simulation division within Arup?" Although many factors affect design, two primary influences have emerged. First, the Arup's original budget did not have a fee structure set up to do the simulation work. In other words, Arup did not have any CFD in the fee proposal. Therefore the design team chose to pursue the Department of Energy (DOE) grant. As described in the earlier case study description, Arup engineer Erin McConahey explained that the collaboration with LBNL was a result of "pre-existing relationships that led to the successful acquisition of the grant." Because LBNL is a research laboratory of the DOE, the "grant was given on the basis of the building being essentially a 'test case' for the LBNL software, as well as benefit to the actual GSA project being built."[6]

Secondly, the simulation software being used in the research institutions was still in development at LBNL. So, having Arup conduct the simulations would not have the dual goal of testing the building and refining the EnergyPlus software. As Phil Haves described, he was still working out the 'bugs' in the software as he was working on the SF Federal Building. "EnergyPlus was developed as a collaborative effort between EETD's Simulation Research Group led by Fred Wilkelmann, the University of Illinois at Urbana-Champaign, and the U.S. Army Construction Engineering Research Laboratory, with assistance from other research organizations. The DOE Office of Building Technologies funded the [Energy Plus] project."[xlvii] "We are the first people to use EnergyPlus to model natural ventilation flows for a major building," notes Philip Haves of LBNL. "Since Berkeley Lab first released the EnergyPlus software in April 2001, the program has been licensed by 12,000 end users, 60 collaborative developers, and five commercial distributors," implying potential for its use as a design tool. [xlviii]

The conclusion that can be drawn from this is that the funding was a result of a very specific client, the GSA, and their vested interest in advancing the research laboratory's simulation tool capabilities. Therefore other federal projects may benefit from a similar relationship, while other clients may have to search for a different source of support.

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[6] email correspondence with Erin McConahey, Engineer, Arup. May 2005.

In another naturally ventilated project, the GSW Headquarters by Sauerbruch Hutton Architects, research resulted in the development of a vent product to assist the cross-ventilation through interior walls. "With its sound absorbent lining, the panel achieves a sound insulation value similar to that of the door."[xlix] (see Figure 51 & Figure 50)

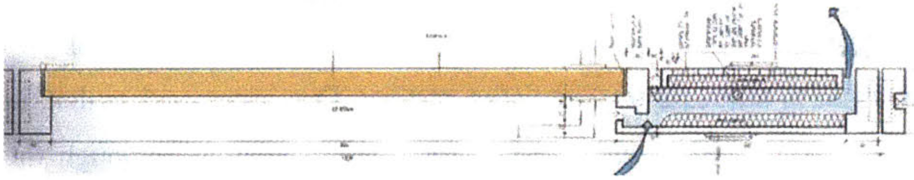

Figure 51: The section through the wall, door, and ventilation panel shows the sound-absorbent lining. *(Modified from Sauerbruch Hutton Architects, 2000)*

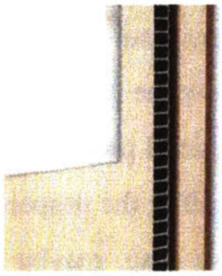

Figure 50: Photo of ventilation panel on the interior wall of GSW Headquarters. *(Sauerbruch Hutton Architects, 2000)*

The application of such a ventilation panel to the enclosed offices and conference rooms would have been relevant to the SF Federal building resulting in even less dependency on mechanical cooling. One might speculate a few reasons that such panels were not chosen in the case of the SF Federal building: perhaps the panels would not provide sufficient airflow; or maybe heat gain from a group of people in the conference room could not be sufficiently cooled by through cross-ventilation; or perhaps the hierarchical nature of the enclosed office demanded air conditioning; or the cost of the ventilation panels was too high. Whichever the case, it should be noted that in addition to doing simulation, collaboration with research institutions can result in product development.

6.1.2 Anticipating additional time requirements regarding green design

The perception that green design requires additional time and resources can deter clients or investors from pursuing sustainable options. By gaining a better perspective on what the time and financial expectations of sustainable aspects such as natural ventilation, designers can better anticipate and budget accordingly. In retrospect, the design team should have budgeted more time or resources to certain aspects affecting the natural ventilation of the SF Federal building. For instance, the evaluation modeling, client presentation preparation, and negotiation with cost estimators were especially influential and more time consuming than anticipated. In the Swiss Re, the fees for the modeling were anticipated but underestimated.

Based on the fact that simulation fees were not budgeted for the SF Federal building, one may assume that the time spent on the simulations was unanticipated and therefore would slow the project down. When asked if the time spent on the simulations hindered the SF Federal project's advancement, Tim Christ of Morphosis said that it did not because they built in the proper margins to allow for the simulation/testing. One can speculate that, in this case, maybe time was allotted in the schedule for some evaluation, although the specific simulation methods were not known at the time the project schedule was created. Budgeting time for undefined research or simulation in anticipation of sustainable goals is an approach that would serve as an effective example for future projects. At the project outset, the design team probably does not know what kind of evaluation or research will be needed for innovative systems. In the case of the Swiss Re building design, some of the simulation services were included in the original project budget. The environmental modeling and concept design evaluation was anticipated, and then fees were requested as certain aspects required further investigation.

Simulation is one aspect of an innovative environmentally-conscious design that might require additional time and resources during the design process. Discussion with Mr. Christ of Morphosis revealed less-obvious time-consuming tasks that architects should be aware of. From Mr. Christ's perspective, the more time-consuming aspects relative to the sustainable design were the approval process and presenting concepts to the GSA. In the SF Federal building, presentation to the GSA required communicating the adaptive comfort methods in relation to the simulation results, while appealing to the client through a life-cycle cost analysis, and explaining the environmental and social benefits. One person on the architecture design team should be responsible for formatting the research supporting the sustainable goals into a client-centric proposal. In addition, this person should be an agile communicator who can clearly express how the design is meeting the client's economic, social, and environmental needs.

The other time consuming process from Mr. Christ's experience was working with the cost estimators (an outside consultant) to give an accurate financial prediction to the client, the GSA. Because the SF Federal Building had items, such as the custom operable façade, that were unfamiliar, the cost estimating team tended to over-estimate the cost. The architect had to engage in a dialogue with the cost estimators to negotiate the actual predicted cost of the systems. This requires a person in the architect's team to dedicate time to researching precedents to compare actual costs of similar building systems. In future projects, time and resources should be anticipated and allocated for this task in the project's original schedule.

6.1.3 Exploring funding options

When asked how this type of project would be approached in the future, Tim Christ from Morphosis suggested that a small percentage of the budget be allocated for the tools to do the simulation and evaluation. While this approach would be ideal, the design team may not even know if they are going to pursue a naturally ventilated scheme at the time that the budget is being decided. One realistic option would be to anticipate and allot funding for the evaluation methods for some "sustainable" part of the project, which could range from natural ventilation to green roofs to photovoltaic installations.

Other design teams can use the San Francisco Federal building's design process as a model for quantitatively confirming the effectiveness of their proposed designs while working within a constrained budget. Although the simulation work was not included in the original budget, the team's awareness of and motivation to pursue a federal grant to support the simulation work arguably made the natural ventilation design possible.

Because the perceived higher cost of pursuing an environmentally-responsible design is a major deterrent to designers and clients, one may assume that the creation of more grants directed at supporting sustainable design initiatives, would facilitate the execution of green designs. The availability and accessibility of such funding resources could be facilitated in two ways. First, these types of grants must be declared a priority by the federal government or other supporting institutions. While policy issues are not the focus of this research, it is important to note that the public and administrative concern for sustainable issues influences the allotment of funding. Precedents for this include the U.S. Department of Energy's Federal Energy Management Program, which funded the simulation of the SF Federal Building, and the PROBE studies, a government-sponsored building analysis initiative in the UK. Secondly, the architect and/or design team's awareness of such resources could be better promoted through industry journals and periodicals or other channels that would reach a professional audience.

Federal policies encouraging environmentally-responsible building give attention and publicity to the issue. "New UK energy legislation arising from the next round of building regulations in 2005 and EU energy benchmarking certification in 2006" will presumably influence future design and construction.[1] In the US, cities and states mandating the application of LEED principles in design is another administrative effort that should reinforce green design. Alongside these policy initiatives, hopefully funding to support such principles will follow.

6.1.4 Garnering Client Support

What can and should the architect do to gain client support of environmental objectives? Even in cases such as Genzyme, where the company's CEO fully supported the environmental principles, the project budget required negotiation and the sustainable aspects required economic defense. One of the keys to gaining client approval was being able to show the client the tangible economic benefits of the proposed scheme. The presentations to the client can be justified from economic and occupant "well-being" standpoints. The reduced energy consumption of all three case study buildings should be an influential selling point to the client. In order to put numbers to the energy-saving predictions, the computer simulation programs can help provide convincing arguments. In the SF Federal building, the makers of the simulation program can now boast about the economic benefits of using their program: "EnergyPlus contributed to nearly $9 million in energy savings projected over 20 years, according to [designers]. The modeling tool was also used to simplify the building's facade, saving taxpayers an additional $1.5 million in construction costs."[li]

In regards to relevancy to future projects, it should be recognized that in the case of the SF Federal building, the client's interest in the life-cycle cost of the building stem from the fact that it will be occupying the building. Therefore they will realize the energy cost savings as well as benefit from the workers well-being in the user-centric atmosphere. Making a case to the client in an owner-occupied building is more straightforward than when appealing to a developer. In a developer-tenant relationship, the developer assumes that the tenant will absorb the operating costs of the building and is therefore only concerned about the first cost. Another case study, the Genzyme building, demonstrates one approach to this relationship where the tenant's extra-ordinarily long lease allowed for input and investment into the quality of the building during design stages. This allowed the client to fund certain green features that the developer alone could not afford. For reference in future projects, it should be noted that the one of the keys in the sequence of events was that the client, Genzyme, was already established when the building was being designed (and could therefore play an influential role in the process), as opposed to the typical arrangement where the developer constructs the building and then seeks tenants. The Swiss Re building is only partially owner-occupied, making its arrangement in-between the entirely client-occupied (SF Federal building) or developer-tenant relationship (Genzyme building). In the case of the Swiss Re building, the environmental principles were applied to the whole building, to the benefit of future tenants. In this case, the design team is not only responsible for convincing the client, Swiss Re, but also communicating to and convincing future tenants how to take advantage of the environmental features. Because the design team probably will not be involved with future tenants, it compiles a packet of information to be relayed through the letting agents to inform them of the natural ventilation and other environmental features designed into the building.

Another aspect to gaining the client's support of the environmentally-responsible strategies was the awareness and understanding of the adaptive comfort standards. These standards were crucial to defining the acceptable range of temperatures within the building and are therefore necessary and applicable to future projects. In discussion with Tim Christ at Morphosis, it was evident that the architect must be aware of these recently adopted standards. Engineering firms less familiar with these standards may or may not suggest their use and therefore the architect must be tapped into such crucial resources.

The client's interest in "sustainable" goals can be facilitated by organizations outside the design team. One option would be to have an outside facilitator coordinate the initial design charrette to make sure the needs of the many consultants and the client are represented in the conceptual design. For instance, the not-for-profit organization, Green Roundtable, located in Boston approaches the facilitation of environmentally-responsible projects by working directly with clients. Hence, consulting services from an outside party may be another key to garnering client support of sustainable objectives.

6.1.5 Conclusions regarding interdisciplinary collaboration

> *"The main lesson learnt [from Swiss Re building] is to get [engineers] involved with the design process as early as possible, preferably at concept stage. Often problems which are highlighted in the modeling are identified at too late a stage and required a solution which compromises the design, usually to the detriment of the natural ventilation scheme. Fortunately Swiss-Re was relatively problem free mainly due to its shape which very well suited to natural ventilation as it works in all wind directions. This late involvement is now changing and architects are becoming enlightened to the benefits of modeling early on. This has come about due to the tightening of the building regulations here which requires buildings to use less energy."*
> *-Ben Abel, senior environmental engineer, Hilson Moran*

Current architecture practice promotes about the coordination and collaboration of many interdisciplinary parties from very early in the design stages. In light of this model, what issues hinder the interdisciplinary collaboration and how was it done in the case studies? Let us assume that a "typical" building design begins with a client brief and the architect's investigation of site, program, and formal language aspirations. It is rare that the architect will approach the engineers with those initial messy designs on trace paper because the thoughts are immature and it will cost precious time and money. It is more common for the architect to devise a semi-complete building, obtain the client's approval, and then ask the structural and mechanical engineers to apply the necessary systems. This approach can have two outcomes regarding the integrity of the design's environmentally-sensitive components. In the best-case scenario, the architect has a good sense of the relationship of the building with the environment and the engineer's role is to optimize the proposed design (i.e. daylighting or natural ventilation systems). In the worst-case scenario, the architect design does not consider the environmental conditions and expects the engineer to employ whatever means necessary to make the building comfortable. Obviously the actual situation is a gradation between the two extremes, but the descriptions make the point that the architect's choices in the very beginning of the design process have implications on occupant comfort, energy use, and the building's longevity.

There is a vital need for architects to engage with the engineers (and in some cases, other parties) from the initial stages of design. As described above, this is not often the case because architects adhere to established patterns of practice or are constrained by time and budget. In another context, architecture students rarely engage with engineers in their design studios to evaluate the site, structure, lighting, or ventilation opportunities. The architect's limited interaction with engineers is recognized by the literature review and industry interviews (Chapters 1 and 2), and the case studies show a model by which interdisciplinary collaboration enables the realization of the environmental goals. Therefore, if the typical players in the initial design stages are the client and the architect, the modified/improved team could include the structural and mechanical engineers, independent consultants, the construction company, and an outside facilitator. Instead of beginning with the lone architect's vision, the design might begin with a charrette involving all parties to establish the main goals and schematic design that addresses the requirements of all parties. At this point in time, it is important to establish clear, realistic targets that the team can collectively work toward. This imparts a sense of responsibility to the team and denotes specific objectives by which to measure their progress. It is also critical that all parties share the vision of environmentally-sensitive design and are ready to address the possibility of increased risk, time, or testing necessary.

PhD research by Massachusetts Institute of Technology graduate Singh Intrachooto suggested that "contrary to popular belief, technological innovation, specifically energy efficient innovation, is best fostered by team members with prior work experience with each other, as opposed to an assembly of individuals selected solely on the basis of expertise." Interdisciplinary collaborations supported by familiarity are also apparent in the Genzyme, and Swiss Re buildings. In the Genzyme building, the pre-existing relationship between the architect and engineer facilitated their collaboration at the earliest competition stage. In the Swiss Re building, the construction of the complicated façade was made easier by the previous collaboration between architect and German cladding contractor, Schmidlin. Their previous work on London's Clay Hall included parametric modeling and digital construction techniques which lent familiarity with one another's working styles in their next project, Swiss Re.

It is important that each member of the design team has a clear understanding of his/her responsibilities and the procedure that should be followed to reach the environmental goals in a timely, resource-efficient manner. Here, Arup engineer, Erin McConahey, responded to my question asking if the firm had a specific procedure for natural ventilation design:

> *I would say that there is no formalized process at Arup that focuses on designing naturally ventilated buildings per se. Our role is to support the vision of the architect and to highlight opportunities available on the site and in the local climate. These opportunities are explored and either adopted as central to the building concept (as in the case of the SF Federal building) or sidelined/rejected for various reasons (as can be found in the design of many buildings). Certainly, at Arup, we always do a climate and site analysis at the start of project, but what arises past that is totally unique to the team and building at hand. If we choose to go ahead with exploring natural ventilation on a project, Arup does have an internal calculation methodology that is meant to ensure that all the analytical aspects of modeling the [natural ventilation] part of building are appropriate."*[7]

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[7] Erin McConahey, Engineer, Arup. Email correspondence, May 2005.

The case study research did not uncover a specific procedure that firms prescribe to implement "sustainable" strategies. The combination of logic and experience guides the process. Perhaps as more firms gain more experience in green design, a customary working style and more formal process will emerge.

6.1.6 Sharing information to avoid re-inventing the wheel

Two types of information-sharing would benefit architecture and engineering firms by allowing them to build on and improve upon each other's experiences. Sharing knowledge of how environmentally-sound features or systems were tested and executed should occur in two realms: [1] through an in-house database benefiting the company, and [2] in industry periodical for the benefit of the larger design community.

Architecture firms would also benefit from a formal system to transfer information on green projects within the firm. Within an architecture or engineering firm, there is a constant challenge to keep up-to-date with current products and strategies, particularly with the number of advertisements and attention around seemingly "sustainable" design. When an environmentally-responsible project is executed within a firm, particularly within a large firm, there should be a way that other members can benefit from previous similar research. There is a resistance to incorporating green features because of unfamiliarity and the perception that extra time and resources will be required. Information on how decisions surrounding green design were made and what criteria were used in evaluating options would be very useful to future projects. In other words, deviating from a standard, non-sustainable practice should not mean re-inventing the wheel every time. Ideally, the green methodology will *be* the standard after some time, but until then, it would be useful to have a reference on how one's peers have done it before. When interviewing practitioners in London, some firms are taking this approach now, devising ways to disseminate information within a firm and share experiences with other firms. For example, while at Ove Arup & Partners, I attended a lunch time presentation where employees interacted with presenters from Michael Hopkins Architects and Arup discussing carbon emissions and energy consumption with respect to specific projects. This discussion included comparison of projections to actual operation and description of unexpected issues that required attention. It can be argued that a combination of this interactive presentation and a written archival document would best serve both architecture and engineering firms' immediate and long-term sustainable goals. . Compiling this information into a searchable database within a firm would facilitate the execution of future green projects. At Max Fordham, UK-based building services consulting engineers, the emerging "sustainability group" within the firm is organizing such a database for the use by their own engineers. This is interesting to examine because even in the environmentally forward-thinking firm Max Fordham, the engineers, Lorna Max and Greg Smith, are volunteering extra time to form the sustainability group, implying that the infrastructure to support sustainable design, even in progressive firms, is still being born. If architecture and engineering firms could dedicate resources to presenting to each other and recording their processes in the form of a document that could be referenced, the sustainable learning curve would be greatly reduced.

In addition to sharing information within the firm, there should be more sponsorship of documentation of sustainable projects for public reference. For example, a conference entitled "Numbers Count" at Yale University in Spring 2004 featured architect/engineer duos presenting projects in which they had collaborated. This combination of disciplines made for especially effective and well-rounded presentations in its description of how multiple goals were negotiated while maintaining the integrity of the environmental ambitions. Architecture journals dedicate glossy pages to beautiful renderings and captivating photographs describing the merits of various projects, and they may even tout their energy-saving or water-reuse projections, but they rarely describe the options and environmental decision process and how the design team calculated their design. They do not describe the various alternatives the design team considered, how they were evaluated, and why one outweighed another. Perhaps this is a fundamental difference between architecture periodicals and scientific engineering journals. Engineering journals take on a narrative approach describing experiments and explaining the reasoning behind them. Because the architecture design process is so multi-faceted, it is difficult to write up as a logical progression of sequential events, and is therefore writings about architecture usually described as it as a product or object. In light of the environmental features emerging in architecture projects such as the case studies discussed here, it would be relevant to isolate and narrate the technical evaluation and design process for those features for use in future projects. By featuring these types of technical narrations in architecture periodicals, architecture firms may feel more inclined to approach a similar endeavor because the perceived risk is lessened and the previous project guides expectations.

6.2 New architect responsibilities

6.2.1 Architect as coordinator

When asked if the design process for the SF Federal building could serve as a model for future projects, architect Tim Christ of Morphosis described the architect's role managing the flow of information via an official written document. While it is common practice for the architect to act as liaison and coordinator of multiple consultants, the number of parties involved in the SF Federal building required the creation of an atypical formal system to organize the information transfer. This document, entitled "Task Management Plan", helped to ensure that the right information was getting to the right people in a timely manner. While the organization of information is laudable, it changes the role of the architect from visionary designer to managerial conductor. Because the environmentally-responsible approaches in architecture design are becoming more commonplace but are not yet standard practice, architecture firms should establish an environmental project overseer/researcher/liaison.

When asked if the firm had a formalized process that would make designing a large naturally ventilated building faster or more profitable, Tim Christ of Morphosis explained,

> "*While every site and every building program affords different opportunities, as architects we have certainly learned methodologies for managing information that can be replicated in our future work. The specific solutions will vary, necessarily, but we are developing a management approach that [ideally] will streamline the flow of work, and increase the accuracy of our final documents.*"[8]

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[8] Email correspondence with Tim Christ of Morphosis, May 2005.

When implementing environmentally-responsible strategies such as natural ventilation in a large building, there is a need for a new position in architecture firms requiring an understanding of the people, timing, and common hurdles in the overall process. Beyond being a pure designer, the architect has a responsibility to address issues regarding consulting, construction, and operation of the building. The objectives of the coordinator role are to lend expertise as well as assume responsibility for realizing the environmental goals. This role is separate from the designer whose primary role is to continually consider and accommodate the many factors with a creative approach. The coordinator role is similar to a project manager in its overseeing capabilities, but emphasizes the inclusion of environmentally-responsible aspects of the project. The coordinator role gains knowledge by understanding other projects and how to adapt and improve their approaches to the current project. The scope of work for the 'coordinator' spans from the project's earliest stages through the commissioning process. The 'coordinator' should understand and recommend the site's environmental opportunities and how they influence initial decisions about building form. The coordinator should assure part of the budget is dedicated to achieving the sustainable goals put forth by the design team and client. In addition, the coordinator should contact and act as a liaison between consultants who lend expertise to the project's sustainable attributes. In many cases, the consultant's area of research could become the source of funding for the project[lii], and the coordinator in the architecture firm should be familiar with appropriate experts. Familiarity with the consultant's capabilities allows the consultant to act as a bridge between them and the architect. For example, knowledge of building simulation facilitates natural ventilation or daylighting design; knowledge of façade assemblies allows integration of multiple lighting, ventilation, electrical, structural, and security objectives; knowledge of other projects with green roofs, photovoltaic panels, water catchment systems, or other ecologically-sound approaches affords the 'coordinator' the ability to recommend and implement the optimal solutions for the project. In addition to technical understanding, the 'coordinator' should know *who* should be involved during the different stages of the design. For example, the coordinator should be responsible for ensuring an interdisciplinary design team; assembling presentation of sustainable goals with respect to the client's needs; securing outside funding to support innovative measures; and administering the inclusion of a post-occupancy optimizing program. The coordinator role can be combined with existing roles within the design team. The important factor is that a specific person is assigned with the tasks. Some design teams may be comprised entirely of environmentally-minded people who will tailor their designs accordingly. While the overall design team may or may not be savvy about the environmental goals, the sense of responsibility imparted on the coordinator helps ensure that the objectives are achieved.

One example that is similar to the coordinator role is narrated as a type of leadership in Singh Intrachooto's thesis on energy-efficiency innovation in the Four Times Square building where a person, outside of the design team or client representation, was hired to oversee the construction of the environmental components:

> *"Pamela Lippe, Earth Day New York, was specifically hired by the Durst Organization to keep a constant eye on the entire process to make sure that the decisions made by different groups were implemented according to the environmental agenda. Even though Lippe did not make design decisions, she became the project's conduit for all decisions; essentially, she became a quality controller for environmental strategies of Four Times Square."*

In this case, the client's commitment to environmental goals allowed it to hire an outside environmental leader. Hiring an additional person could be seen as an unnecessary expense from the client's point of view. It might be more reasonable to assign the "conduit" role to someone in the architecture firm who can play a part in all stages of design and construction and have knowledge of the project's constraints and aspirations. If this position can be named "director", it will have different responsibilities during the different stages of design. First, as initial design decisions are being made, the director can do basic research to evaluate the environmental merits of different proposals. As the design progresses, the director can work with all parties to review decisions in light of environmental goals and suggest improvements. In addition, this person can be in charge of synchronizing the timely flow of information between parties. Once the building is under construction, the director should visit the site often to ensure the integrity of the environmental intent is preserved.

6.2.2 Architect as simulation mediator

At least one person on the architecture design team should understand the capabilities of current simulation software. Since the software is continually changing, this “mediator” position should assume the responsibility of updating knowledge through education. The mediator is responsible for encouraging a rigorous modeling process, and asking for validation through reference to other projects or papers. The mediator can encourage a careful modeling process by knowing the appropriate questions to ask regarding the assumptions made in setting up the model; the criteria for satisfactory answers; and the interpretations of results, all without offending the engineer’s expertise or capabilities. Part of a successful communication dynamic could be developed through collaboration on multiple projects where the parties know and anticipate each other’s working styles.

Whether the building simulation is conducted by a research party or a professional firm, it is important to interpret CFD results with care and rigor. The mediator on the architectural design team should be knowledgeable about building simulation tools, their capabilities, constraints, and accuracy. The architect, when interacting with an engineer engaging in CFD, should not only review the results, but should request validation of those results.

Building services engineers and architects engaging in natural ventilation design would benefit from easily accessible documentation that would validate their current building simulations. It would be convenient to collect in one place journal articles and conference papers that describe others’ attempts to compare simulation results to experimental results. The computer simulation programs’ own websites are not conducive to building industry professionals who are looking for studies that they can compare their results to. Currently, there is no direct source from which one may find similar studies for natural ventilation in buildings for comparison. Having such a source easily available through the simulation company’s own website would promote the value of the tool as well as facilitate the user.

In addition, the coordinator is in a unique position compared to those of the other architects or engineers. As a basis of comparison, imagine the limitations of each party’s knowledge. The architect may not understand the constraints and opportunities of the simulation programs, and therefore not be in the position to ask the right questions. On the other hand, the engineer has limited knowledge of the other design constraints (such as urban, social, or aesthetic goals) that the architect has in mind. Therefore the engineers may evaluate the given design(s), but they lack the breadth of knowledge required to suggest optimal forms or different designs that satisfy the many requirements. A coordinator is positioned to understand the design intent from the architectural side while at the same time recognizing opportunities that arise from the simulation results that could change the form or strategy of the building to achieve the environmental goals. Upon reviewing the simulation results, the coordinator should suggest alterations to the building design or request certain variables be changed and tested again.

6.2.3 Architect as systems researcher

As seen in two of the case studies, unfamiliarity with some of the proposed "green" building systems hindered the advancement of the project. In SF Federal building's case, the cost estimator's unfamiliarity with pricing the operable façade required negotiation and research on the architect's part to achieve realistic estimates. In the Genzyme building, the construction company's unfamiliarity with the raised floor system resulted in perceived risk and an unusually high projected cost for this feature, which eventually got value engineered out. To address these situations in a future project, the coordinator should be responsible for researching the cost and precedents for the proposed systems so that they are not prematurely ruled out. The coordinator is then the architect's advocate and educator with the purpose of explaining why and how the proposed "green" system should be implemented. Alternatively, the coordinator should be unbiased and candid in evaluating if the proposed green system is feasible and logical and should have the freedom to recommend alternatives as well.

Another situation that would require extra research or education is obtaining approvals for aspects of the design that deviate from standard codes. The awareness of the adaptive comfort research in progress required the design team to be alert about recent applicable work. In natural ventilation design, challenging existing codes limiting operable windows or prescribing smoke control methods may require research on the non-traditional proposed design's ability to meet the intent of the codes.

The architect as a coordinator is also poised to advocate for the monitoring and optimization of the naturally-ventilated building after its completion. The coordinator's influence would be to ensure that the original contract designates a responsible party to do the post-occupancy evaluation. If the schedule and funds for the monitoring and optimizing are included from the beginning, this will limit the client's perception that it is an extra, unnecessary item that could be deleted. The opportunity for post-occupancy evaluation is especially relevant in a large naturally ventilated building because the data from the building management system is already being collected, and just requires someone to take responsibility for processing it. Just as the architect should be tapped into emerging comfort standards that help make the case for the building, the architect should be mindful of research such as the PROBE studies that support the need for post-occupancy evaluation and would help make the case to garner client support.

The architect coordinator should facilitate the flow of information in two directions: from the designers to users, and from users to designers. First, he/she should ensure that the energy-use projections made by the mechanical engineers during design are made obvious to the facility managers and evaluation team for the purpose of identifying if actual energy consumption deviates from the estimates. As learned in the Genzyme building, an ineffective steam valve led to much higher-than-predicted utility bills, alerting facilities engineers to the mechanical problem. The operations and maintenance manual's information about design intent should create certain expectations for the facility managers so that they will be alerted if the building is not working properly. At the same time, there should be a feedback system from the users to the designers so that they may learn for future projects. The reality of how the innovative green systems are functioning should be recorded in the firm's database so that it can be referenced in the future. This would be an appropriate forum to note the difficulties in operation so that they can be more cleverly designed the next time. The architect coordinator can be the point person through which this information is gathered and archived.

6.3 The future of simulation tools

The future of simulation tools can be speculated through many different lenses. Here the topics of discussion will include a standard procedure for using the tools, the integration of simulation software into the architecture firm, the development of simulation tools specifically for architects, and the improvement of platform compatibility.

From examining the case studies and the differing comments from industry professionals[9], it is clear that individuals and firms have differing opinions on how building simulation should be used. To illustrate this point, it is interesting to compare the computer simulation process for the SF Federal building and the Swiss Re building. The most obvious difference in the two is the selection of engineers to do the simulation. In the SF Federal building, the design engineers from Arup teamed up with research engineers from Lawrence Berkeley National Laboratory (LBNL) and University of California San Diego (UCSD). In the Swiss Re building, the design engineers, Hilson Moran did the simulations.

In order to apply principles to future projects, one may examine the simulation processes and outcomes for these two buildings through a series of illuminating questions: How did simulation influence the form of the building? Is it used as a design tool or simply for verification of assumptions? At what scale is the CFD used?

From my own, outsider's observation, the simulation was most influential in comparing modifications to original form of the building, and the final building massing did not drastically differ from the original conceptual design. It is clear that the building simulation allowed the designers to make decisions they would not have been able to make purely based on intuition or experience. Therefore, it is significant to note where these tools were influential and where their results provided a deciding factor in design. To my knowledge, the primary urban scale wind tunnel or CFD tests original building massing did not instigate any changes in the overall form. First, in the SF Federal building, the design team tested the effectiveness of adding double-skin "stacks" to the

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[9] Industry interviews described in Chapter 2

south façade to assist the buoyancy-driven airflow. The simulation results determined the stacks were unnecessary, determining the thin, rectangular form without the addition of any double-skin stacks in the façade and confirming the need for sun shading. In the Swiss Re building, the decisions based on simulation results at the scale of the entire building included reversing the direction of the spiraling atria.

It is interesting to reflect on the use of simulation methods either as design tools or as a means to verify assumptions that the design will be effective. In the earlier conversations with professionals in London, one architect, suggested that one might expect three simulation iterations: one to get in the ballpark, a second after the design changes, and a third to know the refined building is performing as expected.[10] While this approach seems logical, the cases of the SF Federal building and Swiss Re show many more simulation runs which include examining the building at many different scales. The SF Federal building used simulation at the scale of the entire floor plate, the window's edge, the window opening strategy, and even the furniture material porosity. The Swiss Re building used simulation at the scale of the urban environment, the floor plate, the six-story atria, the glass dome at the top of the building, the ventilated façade design, and the window operation strategy.

In addition, the strategy to model the urban conditions differed in the two cases. In the SF Federal building, the wind tunnel tests were used to gather the pressure coefficients on the building façade for use in the CFD model. In contrast, the in the Swiss Re building, the CFD studies at an urban scale were done very early in design, and the wind tunnel tests were conducted later for the purpose of verifying the CFD models.

The second topic regarding the future of simulation tools speculates on the use of simulation software within the architecture firm. Traditionally, the specialized simulation knowledge has been confined to the engineering office and therefore the architects hire out for the analysis work. Some firms are changing this model to incorporate in-house simulation work. Tim Christ from Morphosis explained that their firm uses simulation

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[10] Gary Clark, Architect, Hopkins Architects. Interview June 2004.

programs in-house for daylighting and wind studies. The wind tools used in-house have the ability to do bulk airflow simulations for a 3-D model. In Foster and Partners' office, Raquel Viula explained her role as environmental analyst, influencing projects through educating of fellow designers, keeping up-to-date on software, and conducting environmental simulations. Interest in environmental research and technical advancement groups within larger firms is a trend that supports venture into environmental projects through the knowledge of a few specialized personnel.

The integration of building simulation into architecture firms has a few implications, namely it suggests the existence of software accurate yet simple enough to be of use to architects. This thesis began with the assumption that the building simulation tools in existence today are too time consuming, expensive, and require too much expertise for the majority of architecture firms to utilize, even when engaging with engineering firms. Can such an intense process have a place in the architecture firms? Leading firms are already integrating environmental analysis into their practices, giving a market to software designers for tools geared toward helping architects make environmentally-informed decisions. The challenge for simulation tool designers is to make a tool that combines accurate calculation output with simple input requirements all with an interface that caters to an architect audience. Development of such software runs the risk of becoming too rudimentary and giving the architect incorrect or un-influential results.

The purpose of this thesis is not to analyze the individual software packages themselves, but it is relevant to understand the trajectory of future software aimed at architects by examining a three noteworthy examples. The software called Ecotect, developed by Square One, addresses an architect's need for information on climate, solar, thermal, acoustic, and other conditions by providing a visual display of data on which to base early design decisions. The ability to import existing 3-D models and export 3-D models to more detailed programs is one reason it is especially useful in the early stages of design. Another software called Design Advisor, developed at Massachusetts Institute of Technology, is a "web suite of building energy simulators that model energy, comfort, and daylighting performance, and [utility cost] ... intended to be quickly mastered by non-technical designers, and runs fast enough to … experiment with many different versions of a design during a single sitting."[liii] One main advantage of this program is the ability to compare data about various design schemes which can be easily simultaneously graphically viewed on the computer screen. Another tool under development at MIT is MMPN which models airflow and thermal conditions to predict air temperature and airflow rate for natural ventilation in buildings which is intended to appeal to architects because it is faster and simpler than the detailed and computation-heavy CFD model. These three software examples demonstrate how environmental analysis of buildings is moving into the hands of the architect and therefore is creating a new responsibility within the architecture firm to be adept and agile with such tools.

One improvement to the building simulation tools that should take place is enhanced compatibility with modeling software. In both the SF Federal building and the Swiss Re, the architects designed the building using 3-dimensional models. Yet when the engineers evaluated the airflow in the building, they had to rebuild the model in their simulation programs. Ben Abel, senior environmental engineer at Hilson Moran, described his biggest difficulty in executing the Swiss Re's CFD simulations as having to convert the 2-D architectural drawings into highly accurate 3-D models. He describes this frustration as "struggling with mountains of drawings … and having to try and visualize how they all fitted together … before [he] could build that portion of the model."[liv] In our email correspondence, I asked Mr. Abel why the 3-D architectural models could not be imported to the CFD programs, and he explained some of the difficulties:

> *"Unfortunately the 3D models produced by architects are very inaccurate with a lot of extra information on them. For CFD the models need to be 100% watertight i.e. all seams and edges need to meet. Also we often have to 'de-feature' a lot of the building detail to remove small features such as window frames etc. which in scale of the whole building affect the airflow in a relatively minor way. There are software packages which can perform this type of operation but it requires good drawing from the architect in the first place. For these reasons it is often quicker and easier to build the models from scratch using the 2D drawings as templates."- Ben Abel, senior environmental engineer, Hilson Moran*

As Tim Christ of Morphosis describes, because those 3-D models cannot be imported into the airflow simulation programs, there is a missed opportunity to take advantage of the fact that these models are already built - even including façade and furniture. It should be clarified here that, in my experience, a 3-D massing model describing the site conditions may be imported into the airflow simulation program relatively easily. But it is much more difficult to import the architectural 3-D model to simulate airflow into, through, and out of the building. In the future, having one platform in which one can easily interchange models will facilitate the process of building simulation. It should be noted that Ecotect models have the ability to "export geometry and material data to more focused one-shot final design validation tools such as HTB2, EnergyPlus, RADIANCE and others commonly used by lighting engineers and energy consultants."[lv]

In the future, a mutually beneficial arrangement between building simulation software developers and building monitoring/evaluation teams could facilitate the collection of experimental data to verify the accuracy of the software predictions. If there were an agreement between the building managers to share the data on energy usage and aspects such as the number of hours the windows are open, then that data could be compared to the modeling predictions. Of course, there may be a number of reasons why the two might not coincide. Gathering the experimental data is notoriously difficult. As seen in the Genzyme building, even when the data is available, processing it all requires time and coordination of multiple parties, namely the facility manager, the BMS company, and the utility usage monitoring company. It would be ideal, and of benefit to both parties, if the software company would dedicate funding to verification of its modeling by sponsoring a system to compare the actual and predicted data. By collecting this information into one accessible resource, engineers working on similar problems could reference these studies to lend credibility to their predictions. The software companies would benefit from having experimental data to confirm and refine their predictions in buildings. It should be clarified here that software firms are inclined to and sometimes required to show agreement between the program's predictions and carefully obtained experimental data. But it is uncommon find published data comparing the predicted and actual building energy use.

In addition, because occupants often use buildings in ways they were not intended that work against a natural ventilation scheme (e.g. putting up partitions), it would be useful for the simulation companies to compile a number of actual built cases for comparison to the design intent. By collecting these cases side by side, patterns of use might become evident. It would be useful for designers to know, for example, if collected data showed a trend where programmatic changes occurred within ten years and the function of the natural ventilation became obsolete. Or, alternatively, it would be useful to know if the natural ventilation scheme worked for thirty years because then the life cycle cost predictions can be made with confidence. This information could feed back into the simulation programs, accounting for trends in use. As Gary Clark of Hopkins Architects explains, "Using simulation as a presentation tool, it's a nice idea to be able to say 'that's what the building is capable of' and show a range of performance if the client operates it badly." By recognizing that simulation tools may only model the optimal conditions and that many factors contribute to the 'real-life' performance, it would be useful to have collaboration between software companies and building managers to collect and report data on actual performance.

6.4 Future of Post Occupancy Evaluation

In order to understand the future of post-occupancy evaluation, one should build upon the laudable, but uncommon, efforts in the past. The most comprehensive of these is the PROBE studies, which will not be described in detail here because there is plenty of information available through their own website usablebuildings.co,uk. It is significant to note here that the PROBE studies are most useful because of their large database of information. Therefore, the building being tested can be compared against data from similar buildings, and with industry standards for best-practice buildings.

The conclusion from my investigations is that the most common obstruction for post-occupancy evaluation is assigning responsibility for collecting and processing data, and allocating the appropriate funding. The question of "who should monitor the building" is addressed in various ways through multiple projects. This topic is also addressed in an interview regarding high performance facades with Arup engineers[lvi]:

> *Q: Do you follow-up with post-occupancy evaluations to determine if the façade functions as intended?*
>
> *McKinlay: This area is evolving. We would like to maintain a continued relationship with the client, but often our scope is limited to designing the building, not conducting post-occupancy evaluations. The LEED program is really driving the increased concern for performance issues through the requirements of commissioning, measurement and verification. This is also consistent with Arup's interest to evaluate the success of our design, not just the client's . A shakedown commissioning is required of the contractor after six months. Often it takes two seasons to complete adjust and commission the system properly. A walk-through of the building with the contractor is typically conducted after one year, which is when many warranties expire. Typically, we don't get feedback from the client unless there is a problem.* [lvii]

For example, in the San Francisco Federal building, the client, the GSA, hires a specific outside company for the operations and maintenance of their federal buildings. In the Swiss Re building, the design engineers, Hilson Moran, are hired under separate contract to monitor the building's performance. In the Genzyme building's case, the client's own engineers are monitoring and optimizing the building's performance with occasional assistance from the design engineers, Buro Happold. In another instance, the design engineers, Buro Happold, had a three-year separate contract to monitor Wessex Water Operations Center, a project with Bennetts Associates. A less traditional example of post occupancy evaluation is the Building Research Establishment building in the UK where the researchers working in the building were equipped to do their own monitoring.

The difficulty oftentimes is finding the funding for post-occupancy evaluation. Previous government interest in such endeavors like the PROBE studies have provided resources for some time, but are vying for priority against all of the nation's other issues, and therefore funding has waned. Another solution would be to convince the client that a portion of the project budget should be reserved for the fine-tuning of the building systems. This would require data from previous cases demonstrating that this is a necessary and worthwhile process. It further reinforces the need for researchers to publish their data and processes. It should also be conveyed that in large naturally ventilated buildings, the need to optimize the systems is much greater than those with standard mechanical ventilation only. Through the building management systems (BMS) the data collection essentially "free" and therefore needs to be processed into a meaningful form. Future work could include creating computer programs that compare the BMS-collected data to three other systems: the PROBE studies' (or equivalent) database of relevant similar buildings; industry standards for green buildings; and projections from simulation.

6.5 Conclusion

The industry interviews and case study buildings reveal the need for a more streamlined, standardized process for producing large naturally-ventilated buildings. Yet the unique nature of each site, climate, and program suggests re-inventing the design process with every building. The initial questions, referring to building simulation and post-occupancy evaluation, essentially ask, "How does one know the design will work? And, is it working in reality?" This research began with the intent of documenting how cutting-edge firms were using simulation tools, proposing to make them more accessible to a larger design audience and therefore promoting natural ventilation design. As the research progressed, the design process revealed layers of people, complications, and issues critical to the natural ventilation design, making the simulation aspect just one of the many factors that contribute to the success of the natural ventilation design. Although there is promise of future architect-accessible building simulation tools, in my opinion, the expertise of a talented engineer is the most time-efficient and rewarding method of analysis. Tools geared toward the architect are on the horizon and warrant future development, investment, and further integration into architecture firms. At the present time, architecture firms would benefit from architects who are well-informed about the overall process of designing large naturally ventilated buildings. Multiple positions within an architecture firm together must have an understanding of the various parties involved at specific stages of the design, how to negotiate with client and contractor, how to discuss the simulation results, how to research and defend unfamiliar systems, and how to facilitate the flow of information to complete the project in a timely manner. Therefore, architecture firms need not only a technically-astute specialist, but also a management-savvy coordinator to forge the future of environmentally-responsible design.

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