New Technologies and Their Ramifications on Building Energy Codes

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The American Institute of Architects created the Committee on the Environment (COTE) with the specific objective:

> To create Sustainable Buildings and Communities by Advancing, Disseminating and Advocating Environmental Knowledge and Values to the Profession, Industry and Public
> - Environmental Resource Guide

INTRODUCTION

Sustainable design is indeed at the forefront of the architectural discourse. However, the *advantages and disadvantages* of some of the technological advances that have taken place are not well identified, which circumvents the proper mediation of these innovations in the building industry. Recent developments for precise modeling of building energy consumption have shifted focus towards the utilization of Computational Fluid Dynamics: An approach that is promoted to accurately depict – and visualize – the building thermal air flow patterns, including the stack effects, for both passive/active-ventilated double skin buildings. New smart technologies are presently being employed to induce *adequate thermal breathing* of the building skin – *la respiration exacte du mur*[1] – and have led to the development of the intelligent facade.

Being mainly of an European origin, these smart building technologies with their active/weather interactive systems have become more and more popular by virtue of the fact that designers like Norman Foster, Richard Rogers/Renzo Piano, and Nicholas Grimshaw[2] have integrated them into their buildings with high technological prowess. Admittedly, these designers, who have initially operated within the European zone, learned to cope with the more stringent local energy policies, and yet, managed to imbue such technological achievements with poetic value.

Nowadays, their buildings constitute an important source of inspiration as architectural precedents for design students and practitioners as well. Reflecting upon these building exemplars and their contribution to sustainable design reveals a double-edged condition. On one hand, one welcomes the interests expressed towards these designs which bring to the forefront the intrinsic role given to environmental aspects at the conceptual level of the design process. On the other hand, these buildings are too sophisticated for superfluous examination, and quite often, erroneous interpretations are made about the performance initially intended in each of these designed systems. Consequently, the learning gained from such case studies ends up being skewed, ineffective, and not properly applied.

The Energy Code, viewed as the primary source for guidance in the design feasibility of smart systems, does not include these aspects. Due to such a lack of encompassing guidelines, those who think in terms of code compliance tend to immediately dismiss, for instance, the proposed design of a glazed, double skin envelope, presumably, because the building has too much glass, without full grasp of the thermal contribution that the complete system brings.

This paper attempts to examine and enumerate the various discrepancies that exist within the Energy Code regulations, with primary emphasis put on double skin facades and their featured smart control components.

The suggestions made here for developing recommendations are intended only as guidelines to bridge the existing gap between current energy code compliance criteria and those necessary regulations aimed at the prevalent smart technologies. These guidelines will act as the working basis for *knowledge dissemination that warrants environmental feasibility*, as advocated by the AIA Committee on the Environment.

TRADITIONAL COMPLIANCE WITH STATE AND FEDERAL BUILDING CODES

There is a multitude of building codes that architects must consult in order to comply with the building design and energy regulations at the state or federal level.[3] As new technological innovations are proposed, they must be tested to insure that they meet the industry standards of practice. However, the time required to formulate the proper procedure or regulation is sometimes very lengthy. The delays encountered in the procedural review to approve, disapprove or ameliorate new technologies induce asynchronous conditions, that is, an out-of-phase between the new practices applied to energy conserving buildings and those advocated by the code.

Besides some differences identified in code application for various regions in the United States such as climate, the current code enforcement procedures in the energy area remain more or less similar. The minimum requirements prescribed for the single skin building envelope are determined on the basis of the U-value (Overall Thermal Transmittance Value), the conductance value (C value) while the ventilation requirements are determined separately according to occupancy and lighting densities.[4] Hence, depending on the construction system being utilized, the OTTV index can be calculated through the combined, in series and/or parallel, heat transfer flows that occur through the building envelope. Such an approach can be accurately utilized to satisfy the minimum requirements for the conventional building envelope in concert with the assigned window to wall ratio. In many of the existing building codes, the prescriptive path is established for single wythe, multi layered walls and cavity walls, which make up the building envelope. In each of these cases, heat gains and losses are fairly accurately predicted, and are quite simple to determine since the processes of heat conduction and convection are well controlled in terms of prediction. Also, the heat exchanges that occur within the air cavity can be reliably combined into the R-value index, determined as a function of the cavity width. By virtue of its layout, the masonry cavity wall, often interrupted by strip window openings and having narrow cavity width, does not particularly summon serious consideration of stack effects and vertical temperature variation. The same can be said for most double glazed windows where air is assumed trapped under still conditions. Consequently, the prescriptive criteria for homogeneous, composite and cavity walls in the single skin building envelope can be relied upon to achieve the advocated minimum standards of energy gain or loss.

DISCREPANCIES IN ENERGY BUILDING CODE

The consultation of the American Society of Heating, Refrigeration and Air Conditioning Engineers standards – ASHRAE Standards 90.1-1989[5] and ASHRAE 90.2-1993[6] – reveals no specific reference to the dual building envelope, nor is it possible to find clear guidance in *the Principles of Effective Energy-conserving Building Design* listed in Appendix A. The same can be said of the Model Energy Building Code.[7] For instance, ASHRAE Standards in section 8.4 provide well defined design compliance guidelines for every component that forms the building envelope, i.e., accepted energy practices for above and below grade walls, windows. Clearly, such minimum requirements have been established, bearing in mind the conventional single skin envelope. Although section 8.6 offers an envelope performance approach by factoring in the enclosure wall's contribution to heating and cooling reduction, it remains very broad and non-explicit to the designers when it comes to the dual envelope.

The mainstream design culture is fully aware of the prevalence of the new smart technology and recognizes its benefits, but a clear design approach that is accessible continues to elude the designer and architect.

As the conventional building has been dissected as far as the requirement of every component is concerned, so should a clear prescriptive procedure be provided for the various components integrated in the smart dual building envelope. In other words, these existing prescriptive code compliance procedures are hardly applicable to high performance envelopes. In its simplest form, the prototypical dual envelope contains an air space, wider than the maximum 2 inches assigned for the traditional cavity wall, reaching up to 4 feet, and extends through the full height and width of the facade. Therefore, the heat exchanges that occur between the outer and inner skin are not the single result of conduction, but include, in this situation, the important stack and chimney effect which permit air transport of heat into the building or outside. In addition, the smart technologies integrated into this type of building envelope are highly dynamic, and complicate furthermore the ability to employ the current rating even for the peak design conditions. For instance, switchable electrochromic glazing alter their properties as a function of the intensity of the incoming solar radiation. Dynamic systems such as automated venitian blinds, located inside, in-between or outside the building envelope, control also the solar heat gain and the daylight penetration. Some of these integrated systems are autoreactive like the type of glazing mentioned above while others are monitored by the building management system to control louvers that bring outside air to flow within the envelope, or the adjustment of the blind slats according to sun's position. The optimization of the building envelopes requires a careful study of these interdependencies among the many integrated sub-systems in order to achieve energy savings, and reduce peak load demands.

THE BIOCLIMATIC ROLE OF THE SMART DUAL BUILDING ENVELOPE

Numerous designs have already been proposed for the smart and/or dual building envelope which convey either a slight or radical variation from the previous description. As the intelligent behavior pervades more construction materials other than glass, more and more innovations are expected to enhance the bioclimatic function of the intelligent façade. Quoting Mary Pepchinski on quoting James Russel:

> Making the building envelope active in regulating light and ventilation for comfort and energy conservation has seemed only a dream. Not anymore. The [recent] projects....show that clients and designers in Europe are pushing design to a new, higher standard, which may fundamentally affect the way we build.[8]

Indeed, the technology already at hand dictates a new approach to the building and envelope design including all aesthetic and physical properties to be fulfilled by that envelope. For some of the leading design and engineering firms, the new emphases for the overall performance of building envelope are clearly identified. To illustrate the point, this quote from Ken Yeang on quoting Neil Noble of Ove Arup and Partners, reveals the importance of the bioclimatic envelope in building design:

> Sealed boxes are only appropriate for airplanes – buildings are an extension of the land and ought to be thought of as such. The facades of climatically designed building will be fundamental in shaping the interaction between the building and its external environment, as well as creating an internal environment which feels comfortable natural and fresh. Whilst creating this internal environment, the building facade should harness the forces of nature in the most cost effective way. These forces include heat, light and wind.[9]

While the envelope as interactive membrane that filters the natural forces of the external environment is well stated, Noble does not dismiss the important fact that the performance objectives assigned to the thermal envelope must be viewed in relation to cost effectiveness. For these new technologies to succeed, they must be supplied at competitive market values, and be effectively comprehended and applied by the trade and design/construction community. In the following, Noble describes how these integrated systems could be applied to control heat:

> The facade can be used to reject heat that is not required in the building, or to absorb it and redistribute it when it is. Heat could be collected through heat absorbing shading devices, ventilated glass walls, or heat absorbing fluids. Heat could be rejected by evaporative cooling on the surface, or insulated by the use of translucent insulating materials. It could be distributed through integral ductwork, glazed flues or fluid piping.[10]

However, the subsequent issue is the conversion of these principles into some tangible guidelines that the designer could use in an effective way. With respect to light control, Noble identifies various ways that daylight levels can be regulated by the facades. He goes further suggesting technologies of energy conversion to be applied to the facade:

> Light too can be used to improve the internal environment, and the facade can be used to reflect natural daylighting into the building. Various forms of glass including electrochromic and thermochromic glass can be used to control the amount of light in a space. Light can be used in the facade by the incorporation of the photovoltaic cells.[11]

Similarly to the implication of photovoltaic cells,[12] ventilation principles are now incorporated in more advantageous ways into the double skin building, in addition to window opening for cross-ventilation. Noble goes on stating:

> Natural wind forces can be used, sometimes in combination with thermal forces, to improve natural ventilation. The shape of the building and the detailing of the facade can encourage the flow of air, which can help in cooling the building, as well as

providing natural ventilation to the space behind. Overall the facade of the future will be a more fundamental building block, both in low-rise as well as in high-rise buildings. It will take its full three-dimensional form, rather than its current two dimensional form. It will contain systems and components to harness and utilize the forces of nature. It will also provide a route for M & E services and intelligent building systems in the vertical plane, rather than in the horizontal plane, as with current buildings. It will be a much more advanced and multi-functional component than we have today.[13]

The last paragraph illustrates well the marked distinction between the single and the double skin facades, in that the former is more two-dimensionally designed while the latter has become a real three dimensional element that spatially incorporates multiple features requiring special attention to their design.

A few of the many distinguishable designs of smart facades are briefly described below to show how these advanced technologies can contribute to the enhancement of building comfort and energy reduction. The electronic envelope of the Headquarters for RWE AG in Essen, Germany[14] exemplifies the merits of the double envelope whereby the "thermal flue" acting like a buffer zone offers an insulating layer in all seasons and permits control of light and air by individuals and by the building management system. In winter, the buffer zone captures solar heat which can be admitted to offices by sliding open the inner glass wall. In winter, it exhausts excess heat from internal loads and the sun. The de Menil museum[15], designed by Renzo Piano and Fitzgerald in Texas, presents a unique envelope design. Shading of the entire roof is achieved by a glass layer held over a series of concrete leaves. Although this idea was proposed to achieve a desired quality of light in the museum, by capturing the continuously changing daylight, the indoor thermal conditions appear to have been satisfied, even when considering the particularly hot climate of Houston. In fact, the Menil Museum conveys an elaborate system of light control put in place to eliminate the harmful ultraviolet sun rays. For the exhaust of heat that accumulates at the upper level, a ductwork system is inserted between the concrete leaves and the glass. The Hong Kong Bank's[16] sophisticated enclosure incorporates two flue systems with external and internal motorized shading for the control of natural ventilation, solar heat and light.

These examples, among many others such as the Paris Institut du Monde Arabe and the Fondation Cartier designed by Jean Nouvel,[17] reveal the sophistication that intelligent facades have attained. As these technologies become more and more available, the interface between nature's technology and the building's HVAC system technology must be carefully assessed to preserve the path towards energy saving and conservation.

PRESCRIPTIVE VERSUS PERFORMANCE PATH COMPLIANCE FOR SMART FACADES

The idea of applying large expanses of glass comparable to that of the Menil museum cannot be lightly undertaken because the engineers at Over Arup and Partners[18] had to run many complex computational fluid dynamics simulations to achieve full performance compliance with the standard requirements for the city of Houston. It is also understandable that a flimsy application of the principles inherent to the Menil Museum could be counterproductive in terms of energy performance. But in the many case studies on smart facades, glass, for example, appears to better lend itself for the implementation of the intelligent building skin performance, i.e., totally glazed enclosures for a balanced response to light, heat and wind.

The aesthetic and functional qualities of glass have made this material one the primary component that designers enjoy employing in buildings. The major enhancements brought to glass technology in reducing solar heat gain has further reinforced the inclination for further deployment of glass, like the Menil Museum and many other buildings. As more and more improvements occur towards achieving the desired optical and thermal properties of glass, the traditional energy conserving rule of minimal application of glass, to the benefit of opaque material in the building envelope, may no longer be evident when considering the many advantages that such a transparent material offers. Besides, in the double skin envelope other integrated systems in addition to glass, such as air displacement through the thermal flue, shading and ventilation contribute to the control the outdoor/indoor environmental conditions. The point driven here is that investigations are needed to assess the overall performance of these smart facades which have known a substantial use over the last fifteen years, and that clear guidelines and regulations are needed to help architects/designers produce designs that meet the minimum energy requirements. Very little information is covered on the double skin envelope in most of the standard academic and professional literature.

The trend today is to encourage performance based code. For instance, AIA policy now supports the concept that building regulations must be designed to serve performance rather than prescriptive criteria wherever possible. Obviously an immediate answer would be to say that energy simulations exist and, therefore, the architect/designer may consult the engineer in detailing the performance of such applied systems. Unfortunately, this approach is more relevant to the engineer who has a good grasp on the complex algorithmic reasoning that supports the quantified performance of such envelopes. Furthermore, a proper modeling of the energy flows through these double skin facades requires the use of highly advanced software such as Computational Fluid Dynamics which complexity may forbid any easy interaction by the architect. If the design reasoning process is to be properly understood, developing these standards, for the initial design phase does not require simulation tools but tested recommendations on the design application of the smart dual envelope. Particularly, the *Performance Based Code* cannot be solely relied upon but ought to follow the intermediary step of an a-priori defined *Prescriptive Path* that architects can comprehensively utilize when the design development phase begins.

The ultimate challenge is to develop an intelligent code structure with meaningful standards that help fulfill the architects/designers appeal towards smart facades design. Paraphrasing Martin Pawley the editor of the book entitled Future Systems,[19] these systems of facade design have become part of the global mainstream of images that constitute today's design consciousness. The inference from this statement is the need to make these technologies accessible to a wider audience, not just the experts, and that the successful design integration of these smart systems must include the architect. Hence, the guidelines supporting design integration and evaluation process for smart dual building envelopes must find their way into the energy building code which represents the natural instrument of guidance.

INVESTIGATIVE APPROACH TO BUILDING DUAL ENVELOPE PERFORMANCE

As explained above, there are distinctive thermal behavior differences between the conventional single envelope and the smart double skin envelope. New assumptions must be prescribed in order to adjust the threshold of building minimum energy requirements as seen from the perspective of the double envelope. These prescribed requirements for energy code compliance must begin with the identification of a prototypical double envelope applied to a reference building. The selection of this prototype is driven, first, by the examination of the accepted standards of design and construction inherent to the building dual envelope. A re-examination of the role attributed to glass, choice of properties, and operability, must be undertaken, which may lead to assumptions that are radically opposite to those of the current conventional envelope. Furthermore, the proportion of opaque to transparent area within the entire enclosure must also be carefully scrutinized as a major element affecting the overall building performance. Other design parameters to be taken into consideration in the selection of the prototype envelope include operable shading, the spatial dimensions of the thermal flue, and whether low velocity fans are incorporated for air displacement. Obviously, the establishment of a prototypical profile for the building smart dual envelope builds upon the resulting combination of research work done in this area, and the recorded performance of existing buildings. Evidently, the final prescribed minimum requirements must also take in account the many trade offs between the installment cost and the life cycle operation by considering aspects of durability, ease of use and operation of these technologies, including the effective operation of the energy management system. In summary, credible results require further research to be conducted in the domains listed below, some of which were already suggested by Mark D. Levine, David B. Goldstein, Metin Lokmanhekin, and Arthur B. Rosenfeld for the conventional building envelope,[20] but partially adapted to the double envelope investigation:

- Sensitivity studies of air movement and heat transport through the dual envelope flue;
- Sensitivity studies of heat recovered or exhausted through the building envelope;
- Sensitivity studies regarding glass distribution and its impact with respect to facade orientation, size, conservation measures and internal thermal mass;
- Model the contributive impact of motorized shading devices on energy consumption;
- Determine minimum performance requirements for different climatic regions;
- Establish basic operation conditions for the smart dual envelope;
- Identify the various interrelationships between the building envelope components for better thermal behavior prediction;
- Analysis of life cycle costs of energy conservation measures;
- Development of new and comprehensive energy efficiency indices specific to the dual building envelope.

Approach to Code Application

The architect's thrust into the application of building performance-based code must be accomplished through a series of steps that provide the necessary knowledge base. First, informative tools are needed and must be presented in the form of design guidelines and recommendations regarding the application of the smart dual envelope. Then, a section should be inserted in the Building Energy Code(s) containing details on the prescriptive energy performance criteria specific to the double envelope systems. The achievement of these two steps will prepare the groundwork for building performance-based code.

Suggestions on Developing Design Recommendations

For these recommendations to be effective, they must be applicable in the early phases of the design process. For instance, it is at the conceptual level that such recommendations can become decisive in affecting the expected building energy performance. Robust and convenient principles must be established in ways that facilitate design actions by the architect. The ability to comprehend and therefore, find relevancy in these guidelines represents the necessary condition for the architect to naturally participate in the global endeavor of efficient energy utilization. First, rather than looking at the building intelligence as a separate aspect of the project, the architect must consider these intelligent systems as part and parcel of the building given that s(he) must design the areas housing these systems. Besides, the various electronic systems of operations, that are marketed, must be classified and conveyed to the architect according to their purpose, capacity, and the flexibility of the incorporated controls to monitor the operation of the smart facade.[21] Originally, these automated controls, which were primarily designed for electrical and mechanical systems, are now expanded to accommodate a variety of building systems including façade operation. Furthermore, the distinctions that exist between a compartmentalized and a centralized building management system must be identified.[22] Second, a charted representation ranking the various types of smart dual envelopes, and the advantages and disadvantages for specific climates are mentioned. Such a chart can be extended to include specifically integrated features such as the recommended glass distribution within the envelope, including roof and facade orientation. The third aspect deals with the strategic operability of glass windows located on either skin or both of them. Fourth, recommendations must be clearly stated regarding the contribution of the various shading devices when taking into consideration the material they are made of, and their location referent to the building envelope, i.e., inside, in-between or outside. The contribution of the wide range of advanced glazing systems, expected to be weather interactive, are expanding the market and require a clear guidance on their application with respect to the trade-offs between the thermal and daylighting performance. Internal mass thermal contribution must be conveyed in its dependency to solar exposure through the window opening. Finally, the most complex and crucial factor in the energy performance assessment of the building envelope, is the operation and thermal contribution of the flue systems. This last item must be elaborated in relation to the prevailing wind and its direction, and air displacement system through stack effect, pressure difference, or low velocity fans. Consequently, the thermal advantages of the various operative processes of air inducement must be clearly conveyed. Once such design practice recommendations are enunciated within the code, it becomes easier to decide when, where and how a specific kind of smart dual envelope can be applied.

Development of Dual-Envelope Thermal Index Criteria

While these design recommendations may provide initial guidance during the preliminary design, the performance criteria shall be endeavored to insure, then, compliance with code standards of practice. The two primary reasons that have increased the interest in the application of the dual envelope and inherent code compliance regulations have been driven by the following assumptions: glass technologies achieve today a higher reduction in penetrating solar radiation, and that the air system motion to transport heat is a powerful medium of heat recovery and rejection. Comparably to the OTTV index applied to the conventional envelope, a just index that incorporates dynamic effects of the dual-envelope thermal behavior should be produced to gauge the expected performance of the selected components forming the envelope system. A few questions arise with regard to this endeavor. Should the OTTV index be re-evaluated and enhanced in light of the new developments in building envelope systems or should a new index be generated following evaluation of thermal performance in relation to life-cycle cost of the various systems employed in the advanced building envelope? How could such an index or indices be derived? And what design references must be utilized? Answers may be provided if a framework is established to develop, on one hand, the simulation analyses of various incorporated systems and to conduct, on the other hand, survey analyses of existing smart facades in order to evaluate energy consumption trends, thermal performance, and construction practices.

Reference Building Determination

In the identification of the prototype/reference building, the approach defined by ASHRAE should be retained to avoid confusion. The reference building is chosen according to occupancy type and height. However, the a-priori task in identifying a reference envelope appears daunting at first hand and quite complex because of the numerous envelope types designed in many buildings throughout the U.S, Europe, Japan and Singapore.[23] In fact, an endless number of design possibilities have been implemented in response to climatic considerations, technological feasibility and available energy systems. A simple strategy should begin with an extensive energy evaluation of existing buildings, which will help identify thresholds of energy consumption for double skin buildings. These energy evaluations will then generate the basic design characteristics of the double envelope, such as the ratio variation between transparent to opaque surface within the envelope, and the many other parameters listed above: orientation, shading, thermal flue, daylighting credit, internal heat gains, etc. For instance an opacity/transparency ratio, ranging from 0 to 1, will be assigned for each layer of the building envelope. To illustrate this factor, the thermal transmission and solar gains in an opaque inner skin with punched holes for windows and a completely glazed outer skin differ from those of an envelope with each skin fully glazed. As the accumulation of data is completed on the selected buildings, a statistical analysis, similar in approach to that of ASHRAE, will be performed to factor in the contribution of each of these parameters into the *wall heating and cooling compliance value*. ASHRAE's statistical regression equations to derive wall heating and cooling values are specifically directed to the conventional walls. As seen in Appendix A of ASHRAE Standard 90.1 1989, the Alternative Component Packages are also more explicit for the conventional exterior wall than for the sophisticated envelope. The basic changes made to the ASHRAE procedure will be the inclusion of the interactive shading and the thermal flue contribution to the heat transmission and solar gain. The index obtained from the new regression analysis can accomplish a better comparison in thermal efficiency between the single wall and the double skin envelope, and will escape altogether the sole reliance on the OTTV design values. Through this procedure, it may become possible to determine code regulations and standards based on an adequate reference building employing advanced technologies that have been proven to work for the smart dual envelope.

CONCLUSION

The smart building dual envelope is a complex system that registers many factors whose dynamic impact on the overall energy is not yet put in a format that is accessible to the student and the professional in architecture. In this paper, it has been argued as imperative to disseminate new standards and code regulations for the further promotion of smart double skin envelope. A broad outline has been suggested towards the evaluation of the double skin envelope's contribution to the overall building energy use. One area that remains particularly unexplored and misunderstood concerns the thermal dynamics involved in the smart dual envelope. This author intends to explore the impact these dynamics have on the overall thermal performance of the advanced building envelope. The primary endeavor will be to explore a simple dual envelope behavior through the application of computational fluid dynamics and then seek simplified and meaningful interpretations of the obtained results. The following quotation, from the book entitled: *Energy Efficiency in Buildings Progress and Promise*, gives a good summary on the new research trends that these new types of buildings have established: "Smart Walls capable of adjusting themselves to optimize comfort and energy consumption and dynamic buildings able to track renewable forms of energy and avoid extreme forces of nature [sh]ould be developed and tested."[24]

NOTES

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