



INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

IEA Task 27

Performance of Solar Façade Components

*Performance, durability and sustainability
of advanced windows and solar components for building
envelopes*

Subtask A; Project A1:

COMPONENT PERFORMANCE ASSESMENT METHODOLOGY (CPAM)

PART I: ISSUES AND RESEARCH NEEDS

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Dr. Charlie Ćurĉija
University of Massachusetts
Center for Energy Efficiency and Renewable Energy
160 Governor's Dr.
Amherst, MA 01003-9265
U.S.A.

TEL: 1-413-545-4454
FAX: 1-413-545-1027
EMAIL: curcija@ceere.org

1. About this document

The purpose of this document is to identify specific research areas in evaluating performance indicators of solar façade components that can be undertaken within the framework of IEA Task 27, Subtask A, Project A1. It is also the intention of this document to develop guidelines and recommendations how to approach these specific areas in order to accomplish the successful completion of the task.

This document is intended to be complementary to the “Matrix” by Dick van Dijk and “Draft General Energy Performance Assessment Methodology”, by W. Platzer.

This is a new document.

2. Introduction

Building façade components can be evaluated as isolated components, or as an integral part of the building façade, building section, or the whole building. Usually, façade components are evaluated as isolated items for the purpose of energy/thermal performance rating of the product, product development, or simply to learn more about the product performance. Alternately, the façade component may be evaluated as an integral part of the building for the purpose of evaluating the effects of that component on the energy use and other indices of the building. The ancillary effect is how the building and building systems affect the component itself (e.g., forced air heating and cooling systems usually increase the rate of heat transfer from the indoor surface of a window, therefore affecting its thermal performance), and how are those effects in turn affecting back the performance of the whole building. Obviously, some of these effects are occurring simultaneously and cannot be separated, but the analysis of all of them would be prohibitively expensive. This is true now and it is probably true in a near future. Therefore some compromise between accuracy and practicality needs to be achieved.

The rapid development of computer hardware and software technology in recent years has allowed for increased complexity of algorithms and procedures that are used in simulating the performance of building façade components, or thermal performance of whole buildings. Increased complexity until now often meant that user had to deal with complex user interfaces, which are very cumbersome and requiring arduous and time-consuming data preparation process (pre- and post-processing). In addition, various stages of building design and analysis were disconnected, requiring the user to re-enter most of the data necessary to do analysis. However, in recent years there are several initiatives (e.g., Alliance For Interoperability, etc.), which are global initiatives with the goal to reduce disconnect between different stages in building design and to develop standard interfaces between different software modules. With the increased performance of computers, better understanding of the physics of the problem, and utilizing interface standards, it is possible to develop computerized procedures that incorporate very complex algorithms and inner structures, but with very friendly and cost effective user interfaces.

There is a natural tendency to simplify internal operational algorithms along with the overall simplification of user interface. This is unnecessary, however, since we can preserve internal complexities and accurate calculations and even increase them in order to provide for an easy to

use program. This new approach has an obvious benefit; we don't have to sacrifice accuracy of the methodology in order to make things *appear* simple. Another great benefit, which can have repercussions for the work within Task 27, is that we don't have to spend (or waste) our time in developing simplified approaches, when we can use our precious time to further enhance existing algorithms, which may or may not be very complex. Even for an expert in the field, it can be prohibitively expensive to run complex programs in order to find what is the effect of a particular component on the overall energy performance of a building, and therefore he or she may decide not to use it or to use some overly simplified approach. By building “smarts” into program, it is possible to preserve internal complexities while maintaining relative simplicity and ease of use from the standpoint of end user.

For these reasons, in this paper the emphasis will be placed on the development of the “best science” within practical limits of the current state-of-the-art within related mathematical and physical sciences. The purpose of the work within Task 27 should be to push the frontiers of knowledge and science in building energy performance field, and to develop viable methodologies that can be programmed into useful tools for use in building technologies.

3. Specific Research Projects

As mentioned earlier, this paper will focus on the performance of a building façade component and how to improve the methodology of evaluating its energy performance. First the relevant issues and related research areas will be identified, and then the proposed approach in addressing these issues will be recommended.

While the state of the art in evaluating energy performance of solar façade component has steadily advanced over the years, and has resulted in the improvements in standards and performance assessment tools, there are number of issues that remain unresolved or are not in satisfactory state. The issues can be divided according to the intended application of the methodology, and we can identify several areas of application for this purpose:

- Rating and Labeling
- Product selection and comparison
- Product development and design
- Integration of the component into the building

3.1 Rating and Labeling

Energy rating and labeling of solar façade components is being transformed in recent years from loosely defined system, where few representative products are tested or sometimes simulated according to a national standard, to a comprehensive system, which includes performance assessment of a majority of manufactured products according to strict guidelines and certification procedures (e.g., laboratory accreditation program, both testing and simulation, regular trainings and re-trainings of certified professionals, yearly round robins, etc.). This has been possible largely due to an advancement of computer simulation tools, which were both less expensive and more consistent and traceable. Significant and continuing research investments and international

technical cooperation in advanced simulation algorithms and tools, by the United States, Canada and other countries, have lead to new generation of standards (i.e., ISO 15099) and accurate, technically credible computer simulation tools for determining window energy performance, which incorporate these standards. The advancement in computer simulation tools was also substantially due to activities in the past IEA Tasks and Annexes (i.e., Task 18, Annex ??, ???), and it is the expectation that Task 27 will provide significant advancements in algorithms and methodologies that can be incorporated in future computer simulation tools. It is worth emphasizing, however, that the subject of Task 27 in support of energy rating and labeling should be in the development of algorithms and methodologies and not in defining how to set up successful rating and labeling system. Positive experiences, documented in papers and reports, may however become part of background information that can be used by other countries and organizations in developing their own rating systems. Two papers, presenting extraordinary success of fenestration rating and labeling system in United States, is attached here for reference and background information.

The areas that need further attention due to deficient existing methodologies or lack of data are identified below:

1. Convection heat transfer on fenestration boundaries,
2. Local convection heat transfer in sloped and wide spacing façade cavities,
3. 3-D heat transfer effects including radiation heat transfer exchange between self-viewing fenestration surfaces and/or between fenestration surfaces and fenestration attachments, corner effects, thermal bridging, solar effects, etc.
4. Thermal and solar performance of solar façades with attachments,
5. Air infiltration,
6. Use of computational fluid dynamics (CFD) in fenestration computer programs,
7. Precision, Bias and Uncertainty in measuring local temperatures and heat fluxes,
8. Development of additional indices,
9. Emerging technologies,

The following is more detailed description of each particular area and identification of potential research projects to address it.

3.1.1 Convection heat transfer on fenestration boundaries:

Currently, simple average convective heat transfer coefficient is used for thermal performance simulations. While this is true on both sides of façade component, the effect of this simplification is much more pronounced on indoor side, where convective portion of surface heat transfer coefficient represents more significant portion of thermal resistance (i.e., about 50%). This average value is currently either fixed and based on some average reference case (ISO/EN 10077), or it is based on algorithms for natural convection over the constant temperature/heat flux flat plate, which is based on temperature difference/heat flux between glazing surface and surrounding air (ISO 15099). This second approach is more accurate and appropriate for use in computer tools, but it has a deficiency when dealing with projecting products, which have

significant projections perpendicular to the plane of glazing surface (e.g., skylights, green house windows, curtain walls, etc.), due to framing or other components. Also, there is a question of fenestration attachments and their effect on convection heat transfer (i.e., shading devices, etc.). ISO 15099 suggests some correlations for venetian blinds, but work needs to be done to extend these correlations for generalized attachment system and possibly improve existing ones.

Both testing and simulation have uncertainties in convection heat transfer and further research should be done in both areas to resolve these uncertainties.

Measurements of temperature and velocity in a hot box are done at the mid point both vertically and horizontally, with the claim that this represents “free stream condition”. This is not likely to be the case because of mixing that occurs as the air flows over the surround panel and fenestration surface, especially when having geometrically projecting products. Further research needs to be done involving measurements of air flow parameters (i.e., temperatures, velocities, turbulence intensities, flow visualization parameters, etc.), and validating and comparing them with computer simulation for those same geometries. Additional requirements could be developed as for the limits in size of projections in fenestration products and hot box configurations that are appropriate for these systems. Validation of computer models can also be done using IR thermography, interferometry, laser-dopler velocimetry, etc.

Computer modeling of convection heat transfer over the boundaries of projecting products, over the attachments, and in the space between fenestration products and attachments, along with measurements can provide necessary data to develop better heat transfer correlations for modeling these products using practical computer tools. Validation of these modeling works is very important, so it is imperative to develop guidelines for validating computer modeling. The use of emerging techniques in modeling turbulent convection heat transfer should be investigated, especially in the light of emerging computer technology (i.e., utilization of massively parallel computer systems and the development of computer codes to take advantage of this technology, etc.). In addition to average convection heat transfer, it is desirable to investigate local variations in convective heat transfer, as it relates to geometry, presence of attachments and temperature distributions. As a part of research work correlations for local convective heat transfer could be developed, as it will affect comfort related indices, like condensation resistance.

Many fenestration products are installed at angles other than vertical, and there is strong inclination to provide rating indices at the angle that the product is mostly used at. Examples of these systems are roof windows, or skylights, commercial fenestration systems, etc. Both experimental and computer modeling research work needs to be done to determine suitable methodology of performance assessment for these products. From the existing experience, it is apparent that commercial level measurements of sloped products is very difficult and expensive and most of the current efforts are going into the development of suitable computer modeling methodology for handling these products. While some algorithms exist for predicting convective heat transfer on boundaries of sloped products, there is much less information than for vertical surfaces. It is also imperative to develop appropriate methodology for validating computer-modeling results in much the same way as for vertical systems.

Finally, there are many fenestration products with very irregular shapes and geometries (e.g., pyramid skylights, barrel vaults, garden house windows, double facades, etc.). While it is

impossible to develop correlations that would include all possible products, in the case of irregularly shaped products, it is desirable to develop some approximate guidelines about which models to use to represent convection heat transfer on fenestration boundaries of such products. Also, further research should be initiated to cover as many of these products as possible.

Correlations for average and local convective heat transfer on fenestration boundaries can be developed in the form of a library for use by computer modeling tools. This library of standard convection heat transfer correlations could be developed using latest interoperability guidelines by utilizing standard interface format.

3.1.2 Local convection heat transfer in sloped and wide spacing façade cavities:

Local convection heat transfer in enclosures is important to assess condensation resistance potential of solar façades. Condensation resistance is the important emerging index that is related to durability, comfort, and health issues. Condensed moisture on the façade component can accumulate and over time cause degradation and failure. The best example of a façade component that is especially vulnerable to moisture condensation, are fenestration systems. Mold that accumulates because of excess moisture on surfaces that are subject to condensation and freezing can create adverse health environment in the occupied area. Not only can moisture accumulate on the surface, but also it can penetrate cavities and cracks, which are less visible and more likely to cause long term problems.

Local convection heat transfer in glazing and other façade cavities has been investigated in only selected cases, and there are only couple of research papers that deal with this subject in a manner that can be useful for fenestration systems and solar façade components. Since it is still not practically possible to run full CFD computer models every time we want to find condensation resistance potential in a particular fenestration system, especially at high Ra or at an angle other than vertical, it is necessary to develop models that can be used in fenestration computer tools for this purpose.

The research work could produce heat transfer correlations that are dependent on the position in the glazing cavity, in addition to Raleigh number, Ra , and aspect ratio, A . Curcija (2001) has developed a model that is successfully used for vertical glazing cavities being in laminar flow regime. This model or its variants could be extended to turbulent regime (i.e., wide spaced cavities, or large temperature differences or both), and sloped cavities.

Suitable experimental technique needs to be devised to validate computer modeling and future set of correlations. The library model, mentioned under 3.1.1 can be utilized for these correlations as well.

Vertically oriented frame cavities (e.g., jamb sections) are not modeled correctly in current computational models. This is especially true for large and tall cavities. Current correlations need to be updated to more correctly account for vertical convective loop in tall but narrow (in both x and y directions) cavity,

3.1.3 3-D heat transfer effects including radiation heat transfer exchange between self viewing fenestration surfaces and/or between fenestration surfaces and fenestration attachments, corner effects, thermal bridging, solar-optical effects, etc.

It is not completely known what are the extents of 3-D heat transfer effects in façade components. Generally, it is believed that the effect is not that large, because the validation between testing results and 2-D computer modeling results, which are transformed into 3-D results through the use of area weighting and/or linear thermal bridging factors, gives fairly good agreement for most fenestration products. However, the problem is more pronounced in products that are traditionally considered to be projecting products (e.g., roof windows, commercial skylights, etc.)

Full 3-D computer tools that are user-friendly and inexpensive to use, are perhaps several decades away. Issues like user-friendly 3-D geometry creation and automated 3-D meshing, are the most complex tasks. Simulation of conduction and radiation heat transfer in 3-D are relatively straightforward, and represent least problematic areas. CFD modeling, especially in 3-D is big challenge and in addition to the lack of automated error estimation techniques, it poses a challenge to develop a computer tool that would be able to be run by a non-expert user.

Interim solution would be to run selected fenestration system configurations in 3-D using research class computer programs and to develop correlations that can be used in current 2-D computer models. The list of areas for which corrections and/or correlations can be developed in this manner are:

Corner effects: 3-D effects are usually most pronounced at corners, and so it is reasonable to develop corrections and correlations for these regions. In addition to corrections for U-factors, which are allowed to be average quantities, since U-factors are average indicators of the overall window performance, corrections for condensation resistance indicators (CRI) can be developed as well. Because CRI depends on local quantities, like local temperature distribution and relative humidity on indoor fenestration surface, local corrections would need to be developed.

Protruding Hardware: Development of corrections/correlations for 3-D heat transfer effects of protruding hardware in fenestration systems can be done in a similar manner as for corners effects. The form of correlations may be different because of point thermal bridging, that is typical of such elements. Again, average corrections need to be developed for U-factors, while local corrections would need to be developed for CRI.

Radiation heat transfer: Most of the existing procedures and standards use simple "black body" radiation model on the fenestration boundaries for calculation of U-factors or other energy performance indices. On the room (indoor) side, this model assumes that all fenestration surfaces "see" a surface at uniform temperature, equal to the air temperature and emissivity of 1.0. In reality, and especially for projecting (e.g., roof windows, commercial windows) or highly conducting products (e.g., Aluminum profile windows), fenestration surfaces will have significant self viewing, which means that one surface may see portion of the room, but also portion of other frame surfaces. In the corner, where two surfaces are perpendicular to each other their mutual view factor will be actually larger than the view factor to the room surroundings.

The method employing 2-D view factor calculation and radiation calculation between segments on the boundary has been developed and implemented in ISO 15099, as well as in computer codes (THERM). This method makes an important assumption that the surfaces are gray and perfectly diffuse, where each grid segment on the boundary represents isothermal surface. It is not clear what are the implications of this assumption and how large are 3-D radiation effects (i.e., in corners and from other projecting surfaces that are invisible in 2-D models. This method could also be extended to analyze fenestration attachments, like venetian blinds, vertical blinds, drapes, insect screens, etc. Coupled with improved convection heat transfer correlations from the section 3.1.1, the new procedure could provide significantly improved analysis tool for fenestration attachments as well.

Also, it is important to note that this method and associated assumptions are developed only in far IR range (i.e., “thermal range”). It is intriguing if this same idea could be used in solar range, where the radiation balance would be calculated for each wavelength band and extended to include both diffuse and specular effects. The product of this type of analysis could be solar heat gain performance for complex fenestration systems, which could provide alternative to very expensive and notoriously unreliable testing of such systems in solar calorimeters.

3-D solar heat gain effects are currently completely ignored in computer tools. As a matter of fact, even 2-D solar heat gain effects are currently ignored in computer models. By using sophisticated ray-tracing technique and coupling it with 3-D thermal analysis, it can potentially provide full performance model of a complex fenestration product. However, as indicated earlier, even 3-D user-friendly and inexpensive thermal model alone is several decades away, and so is the coupled solar-thermal model even farther away.

SHGC of frames is currently determined using overly simplistic formula that couples U-factor and outdoor film coefficient with absorptance and solar irradiance to produce $SHGC_f$. More accurate formula is given in ISO 15099. This formula correctly accounts for solar heat gain of frames in 2-D, by solving 2-D energy balance on the frame/edge of glass assembly. Extension of this model in 3-D would produce more accurate frame SHGC.

3.1.4 Performance of solar façade components with attachments

Performance of components with different attachments is the area with relatively little existing knowledge. The following is a partial list of different types of fenestration attachments:

- Venetian blinds,
- In-between glazing screens/venetian blinds
- Draperies,
- Curtains,
- Bug screens,
- Complex overhangs/fins,
- Light redirecting devices,
- Attachments like in double facades,

– etc.

Recently, some work in both thermal and solar aspects was done for venetian blinds and the method was incorporated into ISO 15099 standard. These models use some approximations and assumptions, and limited amount of validation was done. Further work should concentrate on extending methodology to generalized attachment. Thermal behavior of a space between the component and attachment need to be modeled using CFD and correlations for both average and local heat transfer needs to be developed. Also, additional research needs to be done in the area of solar effects. Existing model for venetian blinds uses assumption that all reflections are diffuse, which appears to be reasonable assumption up to certain angles of incidence. Extension of this model to account for specular and diffuse reflections, would allow for more generalized methodology which would always be applicable. The use of generalized ray-tracing technique is one of the solutions to this problem. The advantage of using this approach is that it can be extended to any type of attachments, with the geometry of arbitrary complexity.

Further advancement in this area can be accomplished by coupling ray-tracing analysis with thermal analysis. Current thermal analysis tools utilize numerical modeling methods (i.e., finite element method, finite volume method, etc.) and the coupling with solar-optical analysis can be done through the absorbed portion of solar radiation in glazing layers and attachment layers. Good thing is that solar-optical properties are very weakly coupled with thermal behavior of the system, so that it is not necessary to iterate on final solution. It is enough to perform ray-tracing and determine the absorbed quantities in system layers along with directly transmitted and reflected portions, and use those absorbed quantities in thermal analysis. This methodology would provide very accurate results for solar heat gain of the complex system.

In addition to the need for significant improvements in simulation methodologies and development of effective computer tools that can accomplish these simulations, it is also necessary to develop bi-directional property data. This is not a trivial task and further investigation needs to be done to determine the most cost-effective means of developing this data for variety of attachments. Both measurement and computer simulation methods could be utilized in obtaining this data.

The presence of shading devices and other attachments near the edges of will only amplify this problem.

3.1.5 Air infiltration

Air infiltration is currently measured for façade components using laboratory and field conditions and exposing a façade component to a pressure differential and measuring the amount of air that passes through the façade component in a given interval of time. There is no accepted methodology for modeling air infiltration in façade components. This issue is very complex and seemingly un-attainable, because the infiltration will depend on the status of frame components and seals, which often cannot be known in advance. Some idealizations will be necessary in order to accomplish even modest advances in the development of such computer models.

On the other hand, air infiltration plays very important role in component performance assessment, not only in terms of effects on annual energy performance of a building, but also on comfort, condensation resistance and relative humidity of indoor air. For example, the

infiltration of cold winter air through cracks in a window will significantly affect surface temperatures on the indoor side of window, in a near vicinity of the crack. However, this air is usually very dry, thereby reducing the moisture content of air in the vicinity of that crack. Therefore, on one hand this infiltrated air will increase the potential of a window for condensation (i.e., by reducing surface temperatures) while the dryer air near that surface will decrease potential for condensation. These two effects work in opposite direction, and better knowledge about their magnitudes would help us quantify total effect. It is important to realize localized nature of condensation and the need to determine these effects as a function of location on window surface.

In addition to the daunting task of the development of viable computer modeling methodologies for the prediction of air infiltration, novel methods of measuring air infiltration in hot boxes, taking condensation resistance and other local effects into account can be developed, to provide solution until viable computer modeling methodologies are developed.

Sometimes, air is unable to pass through the system from one side to another (i.e., from the exterior to interior side), but it enters for example frame cavities, significantly changing their thermal performance. This effect is sometimes called “wind washing” and affects both U-factor and condensation resistance of façade components. Currently, there are models that account for this effect but they are overly simplistic and there does not appear to be literature supporting their use (e.g., well ventilated and slightly ventilated frame cavity models in ISO 15099). These effects are especially pronounced in commercial framing systems, which incorporate larger frame cavities and with more openings to the exterior.

3.1.6 Use of computational fluid dynamics (CFD) in building façade computer programs

Currently, CFD modeling is primarily used in detailed analysis by experts in that field. The results of such analysis are often converted into correlations for use in simplified tools for analyzing thermal performance of façade components. There are only few notable exceptions where CFD is used directly in the model of façade component (i.e., future room CFD analysis in EnergyPlus, model of laminar natural convection in VISION program, etc.).

The use of CFD modeling in user-friendly tools, which are intended for general user, is very questionable. The reason for this is that CFD modeling still requires high level of expertise in order to get meaningful results. There are several areas that represent problem:

- a) **Uniqueness of the solution:** Very often, the solution of CFD modeling is not unique, and the user can get widely different results depending on the initial conditions, solution technique, etc. and other details that are independent on the physics of the problem.
- b) **Execution time and storage requirements:** Most of CFD models in natural convection require long execution time and fairly fine grid, or mesh. It still takes several days to perform a detailed modeling of a certain modestly complicated system, which is too long for practical use in everyday practice. In addition, it often requires large memory space (ROM), which is typically not available on a computer of an average user.

- c) **Automated determination of flow regime:** Determination of the flow regime at the time of simulation should be automated. There is no suitable automated method to switch between laminar and turbulent regimes and to apply appropriate turbulent model.
- d) **Automated Error Estimation:** Lack of reliable automated error estimation methodologies, makes necessary to have an expert who knows how to prepare good mesh, which is very complex task. Automated error estimation and adaptive mesh refinement is needed, in much the same fashion that some conduction/radiation heat transfer programs work (e.g., THERM).

3.1.7 Precision, bias and uncertainty in measurement methods

Measurement of local quantities: surface temperatures, surface heat fluxes. Large scatter of data between different laboratories. Temperatures at the same location can differ by as much as 10C between different laboratories.

Calibration problems: for projecting products, calibration specimen does not correspond in geometry to roof windows and other projecting products. Other question is environmental temperature for such products.

Investigate effects of the design of test equipment on variations in measured variables.

Flanking energy flow of the fenestration product is ignored in current computational models. Computational models need to be extended to include section of surround panel in order to capture this flanking loss,

Field measurement of actual installation within building. How to do field measurements, and what kind of data to collect. This data should provide answers at how component perform as a part of integrated environment (room, building, etc.)

Use of IR thermography in thermal measurements. Recently, efforts had been made to develop quantitative methodology to measure surface temperature of fenestration products. The claimed accuracy is 0.5C, but further work is needed to uniformly prescribe how measurements and corrections should be done to provide repeatable results.

3.1.8 Development of additional indices

Additional performance indices, like condensation resistance, UV fading, annual energy performance for different climates, etc, help improve both direct and non-direct energy performance and improve durability of fenestration products. Additional, long term research work should yield several more indices that can provide useful information about the product performance. Even though none of them are directly energy related, they have energy implications.

Condensation Resistance: This index has been already developed in United States, but there are still remaining unresolved issues. Most notably, sloped systems and wide glazing cavity IGU systems can not be modeled at this time. The methodology for vertical systems would need further validation and refinement

UV Fading: Currently λ -Krochmann function is used to quantify UV related damage. This function is somewhat controversial and further work is needed to either confirm its validity or new function needs to be developed.

Annual Energy Performance: This is perhaps one of the most controversial indices, because of the inability to develop simple number that would capture performance of a product with respect to annual energy use. The problem is that component energy use or gain will depend on variety of variables, like building it is installed to, climate, orientation, pattern of use, etc. The number of these variables inherently complicate the development of an index.

Daylighting index: This index depends on one of existing indices, visible transmittance, VT. It could either supplant it or replace it??.

Thermal-structural interaction. This interaction can result in glazing deflection and/or stress accumulation in glazing layers, leading to potential failure (i.e., breakage). This effect is currently estimated using relatively crude approximations. Some manufacturers and architects perform expensive computer simulation, using commercially available numerical tools. Current fenestration computer models don't incorporate detailed analysis of this kind. Especially big problem is deflection in commercial glazing systems, where due to the presence of advanced absorptive coatings, large glass areas, and the use of rigid framing systems (i.e., Aluminum, thermally-broken, or not) large deflections lead to significant degradation of thermal performance as well as breakage, accelerated seal failure, and other failures. Deflection can be predicted by utilizing algorithms for thermal-stress interaction and moving boundary numerical models, and can be built into existing 2-D numerical models of heat transfer in fenestration systems.

Moisture migration and premature seal and IGU failures. Collection of moisture in frame cross sections, coming either from rain, or frost/condensation accumulation, as well as humid climates, can cause moisture penetration inside the sealed IGU, causing the failure of the seal structure and low-e coating on one of glazing layers. Possibility to predict this behavior with easy to use and accessible computer tools, can lead to the development of a rating system that would enable consumers to select appropriate product for a given climate and exposures.

Acoustical performance. Acoustical performance is presently done exclusively through expensive testing in life size sound chambers. The cost of such measurement prevents this performance indicator of becoming standard rating index. By developing accurate and easy to use computer tool, which is tied to the existing thermal performance tool, can significantly reduce the cost of the prediction of acoustical performance and enable it to be developed into the rating.

Thermal and Visual Comfort. This is perhaps one of the most important indices, as it relates to human behavior. Question if this is one or two indices.

3.1.9 Emerging technologies

Several emerging technologies are being developed and commercialized in recent years. Examples of these technologies are: Vacuum glazing, integrated wall/window systems, tubular daylighting devices, double facades, etc. In most of the cases, existing measurement and simulation procedures can not deal with these products, and so they have to be left un-rated and

excepted in energy codes. In addition, it is difficult for architects and engineers to predict their performance and their effects on the size of HVAC system, effects on comfort, condensation resistance, etc.

In order to address this problem, it is necessary to identify research areas that would be undertaken, either during the duration of this Task, or during one of follow-up Tasks.

3.2 Product selection and comparison

One of first questions in product selection and comparison is whether this should be done based on isolated component indices of performance or the performance of a product as a part of in integrated environment (i.e., room, zone, or building).

Product selection can be done in one of several ways.

1. By following fixed guidelines and using component performance indices, like U-factor, g, VT, and other emerging indices
2. By using computer simulation tools and utilizing detailed component data, calculated using methodologies developed in A1.
3. Code requirements

3.2.1 Fixed guidelines

This method is most appropriate for smaller buildings where it would be expensive to run computer models, or for projects where it is not quite clear how the building looks like..

3.2.2 Computer simulation tools

This method gives best results, because it takes into account all aspects of a component and building it is installed to.

3.2.3 Code Requirements

Building codes and regulations often have both prescriptive and performance based criteria. Typically, for performance based-criteria, the specific computer tools are recommended.

3.3 Product development and design

Product development relies on the availability of methodologies for performance assessment. The availability of reliable computer simulation methodologies reduces product development cycle and reduces development cost. Typically with measurements, it is necessary to produce physical model in order to measure its performance, and then based on measurements, refine design and produce another iteration of the product. This process is repeated until some optimal performance is achieved. This is usually expensive and time-consuming process, which can be significantly reduced if computer simulation is employed. Iterative design refinements are done in a computer, without the need to build expensive prototypes and tools for producing prototypes (i.e., dies for PVC or Aluminum profiles, etc.)

3.3.1 First item in product development and design...??

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3.4 Integration of the component into the building

Not only the energy use from a product depends on the building and space it is installed to, but also the performance of the product itself gets affected by the integration of a component into the rest of building façade. For example, the performance of a fenestration component is determined under the idealized configuration, where the surrounding panel is constructed out of highly insulating material, so that interface between window and that surround panel can be approximated by adiabatic boundary condition. When that product is installed in a building façade, that interface is no longer adiabatic, and it can be safely assumed that there are significant 2-D and 3-D heat transfer effects which affect performance of both façade component (e.g., window) and the remaining façade. The following is an attempt to formulate a list of issues that result from the integration of a component into a space and building.

1. Wall/fenestration interaction,
2. HVAC system effects on a façade component,
3. Effects of room geometry and composition on a façade component,
4. Effects of humans on a façade component,
5. Feedback loop from the building,
6. Dynamic Effects,
7. Effects of façade component on the other building systems

3.4.1 Wall/fenestration interaction

So far fenestration systems were considered separately from the wall systems in which they are potentially installed. Since fenestration systems are tightly integrated into walls, thermal interaction between a fenestration system and a façade becomes an important issue. There are several effects that can be analyzed at this interface.

- Heat transfer effects of framing on energy flow through interface area (e.g., area immediately around rough opening where fenestration system is installed).
- Heat transfer effects of filling materials (e.g., material inserted between rough wall opening and fenestration system intended to reduce air infiltration and to provide insulation to heat transfer), as well as presence of air pockets and cracks. Effect of trimming techniques and materials, as well as sealing techniques,
- Air infiltration through the interface area,
- Effects of different installation techniques.

3.4.2 HVAC system effects on a façade component

Very often, the layout and usage of a HVAC system affects the performance of a façade component. Whether the HVAC terminals are water or air based, they will always cause air movement in the room, which will affect the thermal performance of the component due to the change of thermal boundary conditions on the room side. Inter-zone air flow, which is often the result from the use of HVAC system, will also affect performance of a façade component.

To assess these effects, it is necessary to define some common HVAC layouts and to investigate their effects on the performance of a façade component.

3.4.3 Effects of room geometry and composition on a façade component

Geometry and construction of the room will have effects on the component performance. The temperature, emissivity, and distribution of surfaces in the room will have strong effect on radiation heat transfer field and convection currents in the room.

This situation can be handled if the whole room, including the fenestration system, is modeled with its true geometry. However, this approach is not currently practical for everyday use. In order to account for full radiation effects, it would be necessary to perform true 3-D modeling, which is a very complex task. Alternative is to perform 2-D analysis of true geometry and then combine results into 3-D. This methodology for converting from 2-D into 3-D results does not exist currently, and could be developed. In addition, CFD modeling can be performed to assess the convection heat transfer in room and building. Different room configurations (i.e., different percentages and locations of exterior walls, different framing systems, different sizes, etc.) could be considered and some correlations developed from this.

Future whole building energy simulation tools could include real geometry of the building and solve full heat balance in a building. Because of tremendous complexities in modeling 3-D geometries, it may be more appropriate for now to model 2-D cross sections, in which some of these realistic effects would be directly considered (i.e., radiation heat transfer with view factors calculation, solution of dynamic 2-D heat transfer equations in real time, therefore capturing effects of thermal bridges and geometric details).

3.4.4 Effects of humans on a façade component

Human interaction with buildings and building facades is quite significant and active. We set temperatures of spaces, we operate windows, draw curtains, we emit moisture, turn on and off lighting, etc. From these activities we affect to some extent performance of a façade component. However, it is not easy to always quantify these interactions, because it is hard to predict some typical behavior and consequences of that behavior.

Start by categorizing and defining typical patterns of human behavior, and then proceed to identify which of these patterns are significantly affecting performance of a façade component. One example is morning showering, which increases the moisture content of the space, therefore increasing the risk of condensation.

3.4.5 Feedback loop from the building

In addition to building and space affecting performance of a façade component, the opposite also can be true. The question is how significant this effect is and if it is worth spending time on it.

3.4.6 Dynamic Effects

We usually look at the performance of façade component as a steady state element, which does not exhibit significant inertia and does not have significant transients. However, this component is a part of dynamic building envelope and Dynamic performance of walls as affected by fenestration systems. Heat transfer resulting from temperature difference of outdoor and indoor air and solar heat gain through fenestration systems significantly affect dynamic performance of building structures. Current computer models for predicting energy use of buildings use simplified correlations that account for dynamic.

Expansion of scope of the existing fenestration computer models to include transient capability (addition of time variable), and ability to handle large structures would potentially provide tool that would enable more accurate prediction of energy use in buildings.

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