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Author

Bazjanac, Vladimir

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**ACQUISITION OF BUILDING GEOMETRY
IN THE SIMULATION OF ENERGY PERFORMANCE**

Vladimir Bazjanac
Building Technologies Department
Environmental Energy Technologies Division
Ernest Orlando Lawrence Berkeley National Laboratory
University of California
1 Cyclotron Road
Berkeley, CA 94720

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Vladimir Bazjanac

Building Technologies Department
Lawrence Berkeley National Laboratory
Berkeley, CA 94720 – U.S.A.

ABSTRACT

Building geometry is essential to any simulation of building performance. This paper examines the importing of building geometry into simulation of energy performance from the users' point of view. It lists performance requirements for graphic user interfaces that input building geometry, and discusses the basic options in moving from two- to three-dimensional definition of geometry and the ways to import that geometry into energy simulation. The obvious answer lies in software interoperability. With the BLIS group of interoperable software one can interactively import building geometry from CAD into EnergyPlus and dramatically reduce the effort otherwise needed for manual input.

The resulting savings may greatly increase the value obtained from simulation, the number of projects in which energy performance simulation is used, and expedite decision making in the design process.

INTRODUCTION

The current standard practice in preparing energy simulation input typically involves repetitive manual operation that in essence amounts to duplication of already existing data. The process is error-prone and the resulting simulation input code is difficult to debug. As the complexity of the building and the simulation increase, input preparation becomes more and more the main catalyst for abandoning (or not even starting) the simulation project.

The largest portion of the effort to prepare simulation input is absorbed by the definition of building geometry. Because few buildings are defined as a true 3-D model, the complete set of information needed to define the building geometry is usually distributed over a large number of 2-D drawings; this requires a substantial effort to comprehend and extract all the pertinent information.

Most architects and engineers depend on the use of some "mission-critical" software in their work. To

execute, such software typically requires information about the building's geometry. In the course of design of a building, building geometry may get recreated as much as seven or eight times or more: Structural, mechanical and electrical engineering, as well as plumbing, energy performance calculation, lighting, code checking and cost estimating software all depend on building geometry information to do their work. In most cases building geometry is completely regenerated because one cannot import the needed definitions directly from CAD files that contain the original information.

When budgeting for building energy performance simulation, one can use the rule of thumb that says that the cost of input preparation and the cost of analysis of results should be approximately the same; relative to these, the cost of simulation runs (i.e., computer run management and computer time) is minimal today (**Figure 1**).

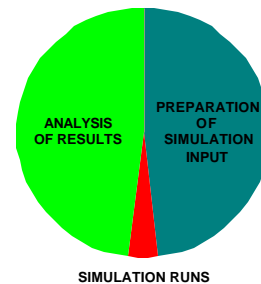


Figure 1. Estimate of typical effort in a building energy performance simulation project.

Simply observing the preparation of different energy performance simulation inputs and runs reveals the typical distribution of effort and resources. Most of the effort in the preparation of simulation input is in getting the first successful run (**Figure 2**). The process that consists of input definition, debugging, and computer runs and analysis of results is repetitive and based on feedback; it often takes many iterations before the result is satisfactory. Subsequent additions and

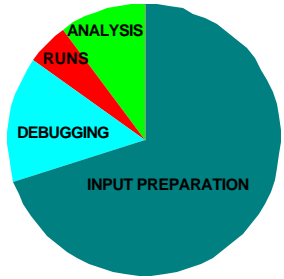


Figure 2. Estimate of typical effort that yields a successful simulation run.

modifications to simulation input that may be needed for parametric runs require comparatively little effort.

In the case of building energy performance simulation, up to 80% of the effort in input preparation may be consumed on the definition of building geometry (**Figure 3**). By definition, most of the building geometry must be defined for the first successful run. The *actual* distribution of effort *varies greatly* from building to building for several reasons: It depends on the complexity and size of the building and its geometry, on the purpose and goals of the simulation, on the expertise and experience of those who are setting up the simulation and preparing the input, on the computer aids that are used in the process, on the schedule and budget, and on several other factors that may affect the case.

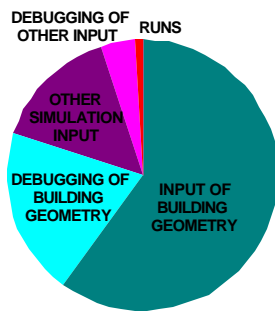


Figure 3. Estimate of building geometry as portion of overall effort to prepare simulation input.

Manual input of building geometry and debugging require continuous high level of concentration and consistency. It is a tedious process that can result in frustration. It tempts one to resort to “approximation of convenience” to “get something running” sooner; that

can cause very serious difficulties later and possibly compromise the entire simulation effort.

In reality, the simulation of building energy/thermal performance is often not used the way simulation is supposed to work in its classical sense: to perform multiple experiments and rely on statistical analysis of results to determine meaningful future outcomes [Naylor et al. 1966]. All too often the investigation of alternatives is limited to one or only a few simulation runs and the results are accepted as definitive answers. Many factors are responsible for that; one can argue that the effort and cost of acquisition of building geometry and the associated high cost of simulation input preparation play a prominent role.

Those who prepare input and use simulation models often dream of tools that could automatically import building geometry. While the completely automatic acquisition may never be achieved, it is now possible to *partially* automate the process and significantly reduce the effort and its cost.

This paper discusses the acquisition of building geometry from the *user of energy performance simulation* point of view. It defines issues from that point of view and discusses some of the options the user has *today*, with the hope that the discussion will lead to less frustration in importing complex geometry into simulation projects. The paper is based on this author’s experience and reflects his opinions – it does not even attempt to refer to and deal with related theoretical and technical (software) issues that have been addressed elsewhere and by others – and focuses only on the pure geometry aspects of interoperability, leaving the discussion of other aspects and issues (such as the topological completeness of representation) for another time.

MOVING FROM 2-D TO 3-D

In regard to the representation of building geometry, sophisticated whole-building energy performance simulation tools are essentially three-dimensional. They all employ three-dimensional coordinate systems and require spatial definitions. BLAST [BLAST 1992], DOE-2 [York and Capiello 1981], EnergyPlus [Crawley et al. 2001] and ESP-r [Clarke 1985] are no exception.

While some architects are beginning to define and document their building designs as three-dimensional models, an overwhelming majority of buildings are still designed and documented in form of two-dimensional

drawings. (One should not confuse 3-D “models” of the building shell for rendering with full 3-D models that contain the complete insides of a building.) There is even sporadic evidence in Europe that some of the early “converts” to 3-D modeling are reverting back to line drawing [Haas 2001].

To an individual that is preparing the building geometry part of input for energy performance simulation, this poses a problem of converting building geometry contained in line drawings to an at least semi-intelligent building model representation. While others have amply discussed this problem, that individual in reality has few choices how to proceed:

1. Interpret the drawings, scale off dimensions and manually key in values that define the location and size of building elements in question, all according to the rules and syntax of the particular simulation tool. This is the most frequently used method to-date. It does not take advantage of software interoperability, and is time consuming and very prone to error.
2. Use a simulation tool with a Graphic User Interface (GUI) that facilitates the definition of the specific building’s geometry for the simulation. This presumes that (a) such a tool is readily available and (b) that the particular GUI is capable of adequately dealing with all the complexities of the particular building’s geometry. If the tool’s geometry definition via the GUI is based on stencils, it is likely that the resulting geometry definitions will be adequate only for the cases where the building layout matches the stencil’s layout reasonably well. The benefit of this method is that, once the building geometry is laid out, the user no longer has to manually enter the data or deal with the tool’s related syntax.
3. Convert the representation of building geometry from 2-D to 3-D *before* it is reformulated for input for the simulation. The difficulties here are that (a) the market currently offers no software that can perform the task *effortlessly*, (b) the conversion to 3-D typically contains much more information than needed for the simulation, and (c) one is still left with the task of importing the now 3-D geometry.

A number of CAD tools can almost automatically generate some sort of a 3-D building representation from 2-D drawings. The approach of some of these tools is rather ingenious: They “prop up” building elevations at the perimeter of the floor plan to create a three-dimensional representation of the building

envelope, or they create three-dimensional models by drawing edges of volumes defined in two-dimensional drawings. While they may be useful for simple visualization, such 3-D models of building geometry unfortunately are not objectified from a building data point of view and are not very useful in thermal simulation.

Potentially much more useful are tools that generate 3-D representations of building geometry from 2-D drawings *interactively*. Such tools require a substantial amount of partially-automated-partially-manual recreation of the third dimension on top of a 2-D representation, but they also typically provide an opportunity to objectify the definitions. A number of such tools has lately emerged on the market.

It is important to remember that manual extraction of information from 2-D drawings is always based on *human interpretation*. Since most line drawing follows well-established conventions of what to represent how, the full three-dimensional understanding of space and objects results from combining information contained in several sources (e.g., building floor plans, sections and elevations). If the consideration of multiple sources is not thorough and tedious, possibly serious mistakes and misrepresentations are possible and sometimes even likely. That makes the extraction of the third dimension from 2-D drawings sometimes a difficult process; the degree of difficulty clearly increases with the complexity of building geometry.

IMPORT OF GEOMETRY DATA

Naturally, if the building geometry is originally defined as a true 3-D model, all aforementioned issues vanish except for one: how to import the given building geometry into the simulation. To do that “seamlessly” (i.e., import building geometry directly from its source without human intervention) one needs an interface between the simulation tool and the source, generator or the container of geometry. In each instance that interface must be able to understand the data structure of both the source application or the database *and* the simulation tool, and must be capable of translating the source information according to the rules and syntax of the simulation tool. Given that this is no small feat and that such interfaces are typically “dedicated” (i.e., they interface only two or a very small number of specific software applications or data bases), this is an expensive and relatively rare solution.

An alternative is to use a simulation tool with a GUI or a pre-processor that can accept 3-D definitions and transform them into parts of simulation input.

Unfortunately, GUIs and pre-processors designed for simulation of building energy performance and currently on the market either cannot directly import complete 3-D definitions of buildings or require manual editing of simulation input.

As always, one can use the manual solution: to read the information from the 3-D model and key it in according to the rules and syntax of the simulation tool. Unfortunately, the probability of error increases with the volume of manual input preparation.

A “simulation view” of the building is different from the architects’ and engineers’. The thermal simulation view of building geometry contains much less information but may demand particular detail that may not have been defined in the architects’ view. For example, some walls, windows and doors, as well as some rooms or spaces may be completely omitted. Yet other walls may have to be subdivided. All such differences must be reflected in the definition of building geometry that is imported into simulation. The following section discusses some of issues that are quite typical for the definition of building geometry for simulation of thermal performance and that make simulation user’s *interactive* intervention in the process mandatory.

REASONS FOR INTERVENTION

A fully developed architectural definition of building geometry typically contains a lot more information than is needed for building energy performance simulation. The reduction of that information mostly involves simplification that requires human judgment and intervention.

The most common case is elimination of those parts of building geometry that are irrelevant to the simulation. Interior walls, interior windows and doors between spaces in the same thermal zone often perform no thermal transfer because in the simulation the temperature is the same on both sides of the construct. If they do not affect thermal mass or daylighting calculation, these and other building parts that have no effect on the simulation can be omitted.

Sometimes many repetitive elements (e.g., multiple individual exterior shading surfaces or windows) have to be grouped into one to expedite simulation execution. For the same reason, repetitive descriptions of identical spaces and surfaces (walls, windows, doors, etc.) are often defined once and then “multiplied.”

More difficult are approximations that are needed because the simulation tool cannot deal with irregular shapes. The best example of that are curved walls and roofs. Few building energy performance simulation tools can define curved surfaces; when such are encountered, they have to be approximated with flat segments. The rules of segmentation vary from one case to another.

For example, Raphael Vignoly Architects PC designed the new David L. Lawrence Convention Center in Pittsburgh, PA with a roof that consisted of three very large curved surfaces. In the modeling of the building for simulation with DOE-2 the roof geometry had to be approximated with 70 flat horizontal segments (**Figure 4**). The approximation had to accommodate 14 long skylights positioned across the roof. In addition, the geometry of all vertical and sloped glazing that extended to the roof had to be reconfigured to properly simulate the shading effect from the roof. Finding an acceptable approximation took more effort than the definition of the rest of that building’s very complex geometry.

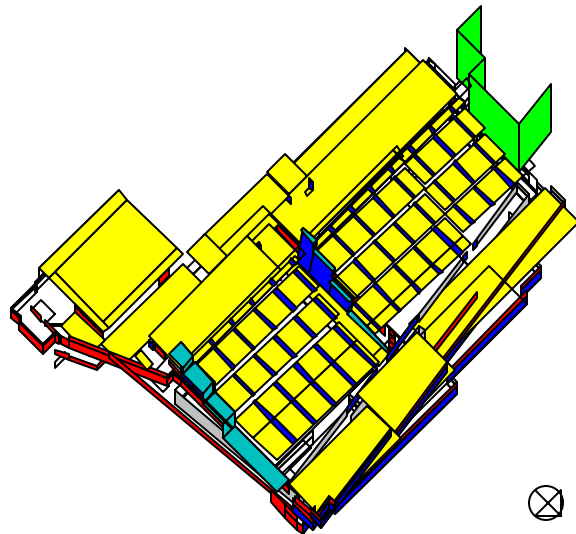


Figure 4. Flat segments that approximate the curved roof and skylights of the new Pittsburgh Convention Center, as shown with DrawBDL.

Some of the information that is part of building geometry is sometimes not included in CAD drawings or must be developed specifically for the simulation. For example, architects’ drawings and building models seldom define plenums above floor space explicitly as separate spaces; these often *have* to be defined as separate thermal zones for the simulation. Or it could be the (3-D) location of sensors perhaps endogenous to the simulation that monitor and control events in the

simulation, such as sensors that control the use of electrical lighting. Or the different coloring and surface treatment of otherwise the same wall may require the subdivision of the wall for proper definition of reflectance at different locations. The missing information must be developed and added to the building geometry input.

Thermal zoning for simulation usually requires agglomeration of spaces that share the same thermal conditions and are operated in the same way. In other words, two or more spaces in the building are merged into one thermal zone. Given a complete HVAC design for the building, one would expect that this task could be automated and made an integral part of building geometry input for simulation. This is not always the case, because decisions about thermal zoning may require the consideration of other factors, such as occupancy characteristics that may result in different internal schedules and loads in otherwise identical spaces. The consideration of daylighting also affects zoning decisions. Such cases always require human user judgment, decisions, and modifications and additions to the original definitions of building geometry.

CAD tools have shortcomings, too, regardless of how sophisticated they are. A few are not able to properly define all shapes and volumes one may encounter in a building. Others have apparently useful advanced features that are not adequately documented. And yet others have advanced features that have not been fully debugged. To effectively help in the preparation of input of geometry for simulation, *all* require sophisticated, experienced users. Inexperienced users can get bogged down in trying to properly use the CAD tool and are often better off not using such tools until they acquire sufficient skills.

GRAPHIC USER INTERFACE

While the number of available whole-building energy performance simulation engines is still quite small, the number of simulation tools on the market seems to be proliferating. Most new tools incorporate an existing simulation engine with a GUI and a post-processor that make the use of simulation in many ways more convenient. Unfortunately, few of these GUIs are designed so that they completely facilitate the definition and/or import of building geometry.

A GUI *truly* useful in the acquisition of building geometry should be able to:

- Deal with *any arbitrary* geometry, and deal with it *in 3-D*. This is a “non-negotiable” requirement: While stencils are helpful and may save time when used, most complex buildings’ geometry *cannot* be properly “shoed-horned in.”
- Read CAD files in their native format. That eliminates problems that arise from image translation, such as layer control, line color and weight, font type and point, etc., and makes working with the original information easier.
- Facilitate the use of layers and overlays. It is good practice to make all simplifications and additions to building geometry on separate layers and/or overlays. This pays off increasingly as the simulation input develops and expands.
- Support simultaneous display of multiple drawings and views. This saves time in detecting errors.
- Include a fully functional ASCII text editor that can expose the simulation tool’s input syntax. That permits simple corrections or additions to the input that are often accomplished quicker with a text editor. It also facilitates the copying of segments of input from other simulated buildings that are appropriate to reuse.
- Support copy/cut-and-paste among multiple documents. This is useful when incorporating information from files in different format.
- Provide seamless access to external databases and libraries. Some of the building components that have geometry are defined in manufacturers’ and/or other databases and libraries and carry information in addition to geometry that can be used in the simulation.

In the absence of a GUI capable of doing that, one can use almost any sophisticated and fully functional 3-D CAD tool as a substitute. Current releases of such tools can perform all functions listed above as the requirements for GUIs to assist in the acquisition of building geometry. The drawback is that the user must be highly skilled in the use of the particular CAD tool to use it effectively for this purpose.

SOFTWARE INTEROPERABILITY

The obvious answer to acquisition of building geometry from CAD is *software interoperability*: direct exchange of data among different software applications. Such exchange requires a common data model that is shared (or at least “understood”) by the exchanging applications [Bazjanac and Crawley 1999].

The idea is not new. The International Alliance for Interoperability (IAI) has been developing an objectified data model of buildings for more than six years [International Alliance for Interoperability 1999]. The data model is called the International Foundation Classes (IFC) and its latest version (IFC 2x) was released in October 2000. This data model fully supports the three-dimensional definition of building geometry. In addition to other information, software applications and tools that have implemented the IFC data model and are “downstream” in the design/analysis process can directly import building geometry that was generated by “upstream” CAD tools. They can also modify it and send it back “upstream.”

A group of industry partners formed a joint project, Building Lifecycle Interoperable Software (BLIS), to develop interfaces to own commercial software in support of specific industry processes. The exchange of data is based on the IFC 2.0 version of the object data model. One of the supported processes is design-to-building-thermal-performance-analysis. It is now possible to import building geometry from CAD tools via middleware into EnergyPlus 1.0. The linking middleware are the BS Pro COM-Server, developed by Olof Granlund OY in Finland [Karola and Lahtela 2000], and its EnergyPlus Client, developed at the Lawrence Berkeley National Laboratory. Both are bundled with EnergyPlus.

The process is illustrated in **Figure 5**. If the building is only documented in 2-D, CAD files are imported into a CAD tool (such as Visio 2000 Technical or Visio 2002 Professional, ArchiCAD 6.5, Bricsnet Architecturals or

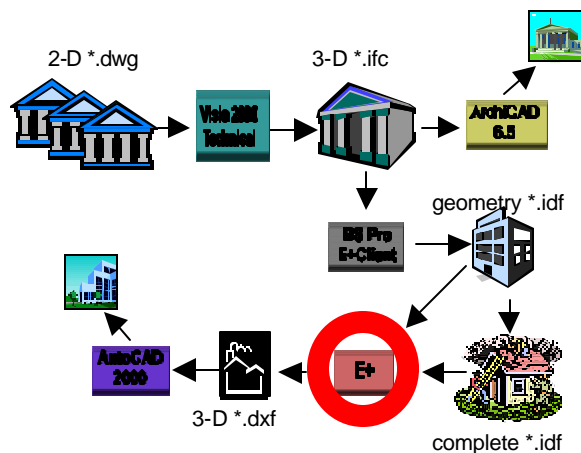


Figure 5. Flow chart of the BLIS process of importing building geometry from CAD into EnergyPlus (abbreviated as E+).

Architectural Desktop 3.3) to interactively add the third dimension and save it in the *.ifc file format. The *.ifc file format is the file format used in data exchange among IFC-compatible software applications; it is fully compliant with the ISO STEP Part 21 specification [ISO 1994]. If the building is originally defined in 3-D, the process begins with the saving of data in the *.ifc file format. BS Pro COM-Server imports the *.ifc file and the EnergyPlus Client extracts from it all building geometry definitions needed for simulation with EnergyPlus. The Client also arranges the information according to the rules and syntax of EnergyPlus and saves it in EnergyPlus input data format, *.idf. That file contains only building geometry information, but EnergyPlus can import it and verify its correctness: It generates a *.dxf file that can be displayed in any CAD tool that can import that format. The content of the geometry *.idf file can then be spliced into an *.idf file that contains the rest of the data needed to execute a complete EnergyPlus simulation.

POSSIBLE SAVINGS

The definition of geometry for the DOE-2 simulation of the David L. Lawrence Convention Center (**Figure 4**) was difficult and took more than three man-weeks to complete. One has to wonder how much could have been saved had it been possible to at least partially automate the process.

To get at least some quantitative understanding of the possible savings, BLIS partners developed a test building: a three-story office building of modest architectural complexity. 2-D floor plans (drawn with AutoCAD 13) were imported in Visio 2000 Technical to modify the geometry for energy performance simulation and to extrude the entire building vertically. In this case Visio software served as a substitute for a GUI. The resulting *.ifc file was visually tested with ArchiCAD 6.5 (**Figure 6**), “spellchecked” for model correctness with Solibri Model Checker, and then imported into BSPro. The BSPro Client for EnergyPlus then generated an input file for EnergyPlus that contained building geometry necessary for the simulation. An EnergyPlus simulation run of the input file with geometry created a *.dxf file; it confirmed that the building geometry was imported correctly (**Figure 7**).

The entire effort took a little more than three hours. In the opinion of the author, it would have taken an experienced user 12-16 hours to define the geometry, import it manually and then debug it. This indicates a

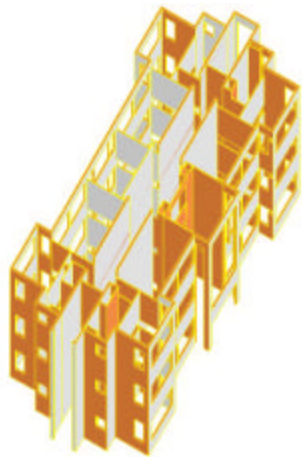


Figure 6. BLIS office building; floor and roof slabs are removed to allow the inspection of all vertical interior surfaces (view generated by ArchiCAD 6.5)

savings ratio of between approximately 1:4 and 1:5 for a building of modest size and complexity. Larger and more complex buildings should yield even higher ratios. Savings resulting from direct acquisition of building geometry can impact a project dramatically and in several different ways.

IMPACT OF SAVINGS

In reality, many building energy simulation projects never fully reach their objectives. The setup of the simulation costs so much time and money that the remaining resources are sufficient to simulate and examine the impact of only a handful of alternatives. A 70-80% reduction in the cost of building geometry definition can reduce the overall simulation setup cost by as much as 55-65%. The savings can then be applied toward the simulation and evaluation of performance of additional alternatives. Some of the savings could even be distributed to other tasks on the project. And, of course, many simulation projects that are too expensive under current practices can suddenly become economically feasible.

Perhaps even more important is the possible impact of time saving on the building design process. One of the main drawbacks in using energy performance simulation in support of building design is that simulation results typically lag in time: By the time the simulation of a state of building design has been finished, the design has already moved to a new solution or alternative. Decisions on issues raised in

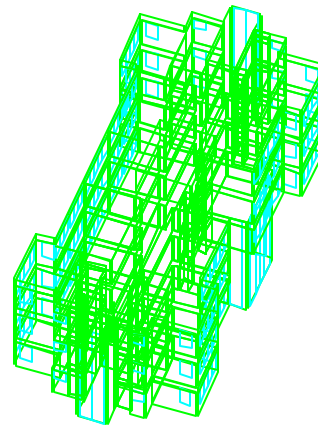


Figure 7. BLIS office building geometry verified with EnergyPlus (output from EnergyPlus: wire frame isometric in the *.dxf file, displayed with AutoCAD 2000i).

one meeting usually have to wait until another meeting in the future, because it takes so much time to prepare and do the simulation before the results can be analyzed. With software interoperability it may now be possible to prepare and execute the simulation, analyze the results and make the decision in the same meeting.

A number of architectural and engineering organizations have expressed interest in using these tools in real-life projects. BLIS partners will support such efforts. These projects will yield further understanding of the possible savings from direct acquisition of building geometry. They are also expected to provide user feedback that will result in valuable improvements of BLIS interoperable tools. And participants in these pilot projects will form the beginnings of a user base that has experience in direct acquisition of building geometry from CAD into simulation tools and other downstream applications.

CONCLUSIONS

The ideal of “automatic” acquisition of building geometry for building energy performance simulation is not at hand. The difference between the “simulation view” of the building and the view shared by architects and/or engineers is too varied and too significant. The concept of “pressing the button” to generate and import geometry is not realistic: *Human intervention is unavoidable* if the generated building geometry is to properly define the building to the simulation.

Yet, tools exist today that can automate *parts* of the process of definition and import of building geometry. These tools can expedite the process, avoid most errors and make the overall simulation effort much more productive. Ultimately, this may result in a much more frequent use of building energy performance simulation and in better buildings.

ACKNOWLEDGMENT

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