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HAL Id: hal-01088902

https://hal.science/hal-01088902

Submitted on 29 Nov 2014

2013 ISES Solar World Congress

Evolution of CODYRUN from thermal simulation to coupled thermal anddaylight simulation software

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Abstract

CODYRUN is a multi-zone software integrating thermal building simulation, airflow, and pollutant transfer. Described in numerous publications, this softwarewas originally used forthe passive designof buildings, both for research and teaching purposes.In this context, the datatreatedwere mainly concerned with volumes (zones), surfaces andthicknesses (walls andwindows), materials, and systems, with the aim to determine temperatures,heat fluxes,energy consumed, air transfers, and so on.

The questionthus arose as tothe integration ofindoor lighting conditions into the simulation. Hence, previousdata structureshad to beamended to incorporatethe spatial positioning ofentities (walls, windows, and artificial lighting sources) throughvertexes. A set ofprocedureswasalso developed for polygons as well as calculatingnatural and artificial lighting.

The results ofthis new daylighting modulewere thencompared with otherresultsof simulation codes and experimentalcases both in artificialand naturalenvironments. Excellent agreements were obtained, such as the values for luminous efficiencies ina tropical and humid climate.

A simulation exercise was conducted in a classroom located in Reunion Island (French overseas territory in the Indian Ocean), thus confirming the interest for thermal and daylighting designsin low-energy buildings.

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1. Introduction

Several software packages are available for thermal and airflow simulation in buildings. The most frequently used are ENERGY+[1], ESP-r[2],and TRNSYS[3]. These applications allow an increasing number of models to be integrated, such as airflow, pollutant transport, anddaylighting. In thelatter category, we may note E+, ESP-r,or ECOTECT [3] software.

After more than 20 years of developing a specific code named CODYRUN, we decided to add a lighting module to our software.This paper therefore provides some details on this evolution and a practical application.

2. From thermal simulation to daylight model

Developed by the Physics and Mathematical Engineering Laboratory for Energy and Environment at the University of Reunion Island, CODYRUN [5-13] is a multi-zone software program integrating ventilation and moisture transport transfer in buildings. The software employs a zone approach based on nodal analysisand resolvesa coupled system describing thermal and airflow phenomena. Consequently, the ambient thermal comfort is estimated for buildings' systems. In these energyand comfort calculations, the precise location in spaceof a building's componentsshould be noted, which is not usually helpful, with some models even requiringgeometrical information,such asthe height of openings [7] or solar masks [9].

At this step, the datatreatedwere mainly concerned with volumes (zones), surfaces andthicknesses (walls andwindows), materials, and systems, with theaim to determinetemperatures,heat fluxes,energy consumed, air transfers, and so on. Details of the CODYRUN data structures are given in Lucas et al. [13] although details on the internal organization are not so common, with the exception of ENERGY+ [1], ESP-r [2], andCOMFIE [15].

2.1. Initial data structures

As displayed in Figure 1, the building is assembled from various components: zones, walls, windows, heating, ventilation, and air conditioning systems, openings, vents, and so forth. For each of these components, the window description helps users to complete the information for the associated data structures. In the example of a wall, the user must enter its surface, constitution (layers, materials, and thermo-physical properties), and radiative properties. The description of the windows and structures was previously described inBoyer et al. [5, 14].
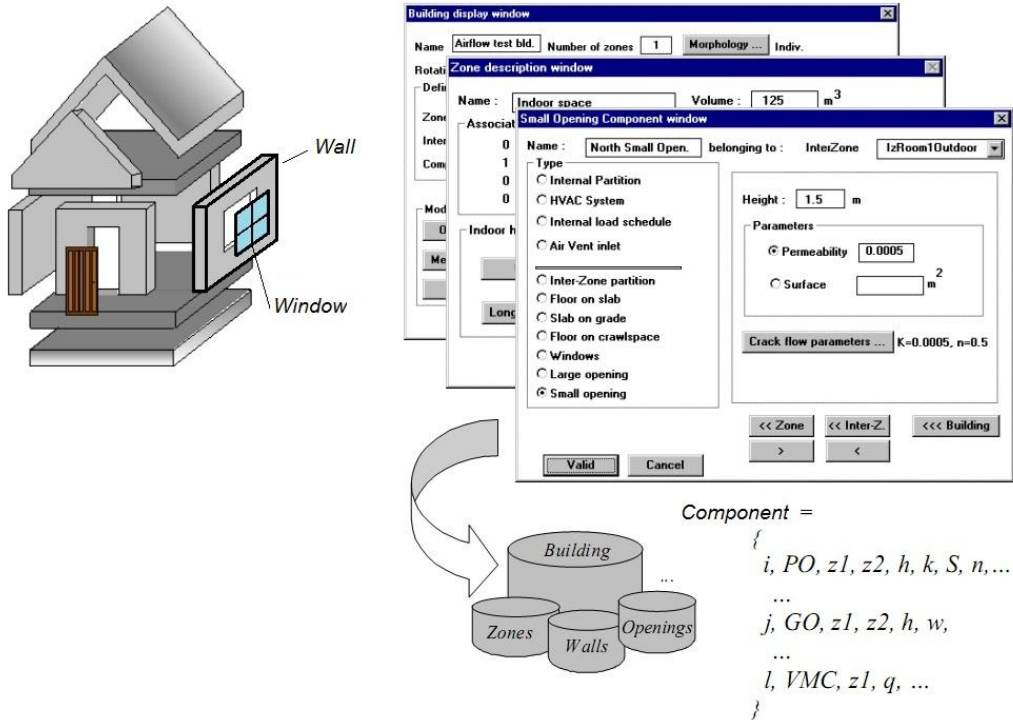
Fig. 1. (a) Component assembly of a building; (b) Associated windows and structures

2.2. Modified data structures

Taking into account the lighting calculations[21],thespatial positioningof the data relating tothe walls, windows,apertures,andartificial illuminationwas required. Previousdata structures describing these elementsthus had to beexpanded to incorporatethe spatial positioning ofthe entities (walls, windows, and artificial lighting sources) throughvertexes. Three types (in terms of C language data structures) were introduced, namely *point*, *polygon*and *block.*

*Point*was linked to the coordinates, *polygon*described a set of points (maximum of eight),and *block*comprised two polygons. The corresponding C structures were thus as follows:

```
T_Point              T_Polygon                  T_Block
{                    {                          {
  floatx,y,z ;          T_PointLstPts[8] ;         short nTypeBlock ;
}                       short nSensDesc;           short nNbSommetsBlock;
                        short nTypeSurf ;          T_Poly Poly_1;
                     }                             T_Poly Poly_2 ;
                                                 }
```

To ensure the spatial descriptionof elements,thislast data structurewas incorporated intothatof the componentsdescribed in section 2.1.In the current version of CODYRUN, all of these coordinates areentered individuallyusingthe windowdescriptions. After aspecificsoftware development, thesedetails

will soon beretrievable fromGoogleSketchup®andOpenStudio®. Then, newcomponentsfor lightingwere introducedfor artificial lightingandlightpipes.

Each component of the building is thus viewed as two polygons,each containing a certain number of points. For rectangular glazing, the structure is composed of two rectangular polygons each with four points. The first polygon is the inner face and the second the outer face. Lastly, each of the points of the two polygons is plottedin space using its three coordinates (x,y,z). An example of the four points ina polygon (P1 to P4) is given in Figure 2a for an external opening.

Concerningan artificial lighting source,such as a light bulb, byallowing its assimilation to a point source, the coordinates of a single pointmustbe defined(i.e.,those ofthe point source).

2.3. Daylighting models

All availablemodels requirerelative spatial positioningofthe elements(floors,windows,openings, andlight sources) to calculate the receivedlight on each pointinthe working plane (or mesh).

The daylight factor (DF) classical method was used to calculate the diffuse illuminancefor all of the mesh points. This method was elaborated by the British Building Research Establishment (BRE) and published by theChartered Institution of Building Services Engineers (CIBSE) [16]. The diffuse light falling on one point in a roomis commonly considered to be composed of three distinct parts: the sky component (SC), externally reflected component (ERC), and internally reflected component (IRC). These values were calculated for each point of the defined mesh using standard formulas. Thedirect illuminationwas obtainedby projecting theedges of theglazing andthe outer apertures eventually illuminatedby directsolarradiation in order to calculate the indoor sunspot.

2.4. Geometrical considerations and polygons

A set ofrelatedC procedures relative to the geometry ofplanar polygonswas incorporated into thecode based on previous research[2, 17, 18]. Itrelates to,for example,the calculationof surfaceperimetersfor polygons, the distance betweenapoint and a plane, testing the inclusion of apoint in a planeor polygon,orprojectionsrelatingto shadingcalculationsandthe sunspot.

3. Validation of the model

Numerous validation tests of the CODYRUN code were successfully applied to the software. Apart fromthe daylighting model, the majorityapplied the BESTEST procedure [8] and led to the validation of the outputs.

When dealing with the daylighting simulation model in particular,it was difficult to achieve the prediction accuracy. It is thus necessary to refer to some rigorous and recognized procedures used around the world. However, there is limited documentation on the procedures to follow. In most cases, laboratories implement their own experimental database to serve as a reference for comparisons between model predictions and measurements. The study ofMaamari et al.[19] responded perfectly to our needs concerning the validation step. Indeed, this theory establishes methods to verify the reliability of simulation codes for indoor daylighting and artificial lighting on the basis of analytical and experimental tests cases. This work was used as a reference in task TC3-33 of the International Commission on Illumination (CIE).

Many other test cases found in scientific literature (publications from the French Scientific and Technical Center for Building, BRE, International Energy Agency's Task 21, and experimental test case from CIBSE, etc.) were applied to the CODYRUN simulation software. An inter-software comparison

was also conducted, and finally, database references for the local study in dynamic conditions (from a cell called LGI) were established [11].

4. Case of a classroom in Reunion Island

A simulation exercisewas conductedon aclassroomin our university. The aimwas to usethe integratedmodelto enable students to understand natural and artificial lightingphenomena through variousdynamic simulations(annual, monthly, and daily) in order to characterizetheindoor lighting conditions and improvethe visual comfort of the room.Some resultsfrom Fakra's study [21] are presented inthe following paragraphs.

TD2 classroom (see Figure 2) is located at Saint-Pierre (Latitude: 21°19' South, Longitude: 55°28' East. Altitude: 68 m). The climate is tropical and humid.

The dimensions of the classroom are as follows: 7.2 m in length, 6.74 m in width and 3 m in height, with a totalvolume of 145 m^3. Two large windows are located on the west side of the classroom and three others on the east side (one small and two large openings). The dimensions of the large openings are 1.1 m high by 1.5 m width, compared with 1.1 m high by 1.2 m width for the smaller window. Three doors, positioned respectively to the south, north, and west of the classroom,each measure 2.1 m high by 1 m width.

The reflection coefficients of the walls, ceiling, and floor were estimated at 80%, 70%, and 60%, respectively. The transmission coefficients for the single-glazed windowswere 85% (given by the manufacturer), while the reflection coefficients of the doorswere estimated at 70%.
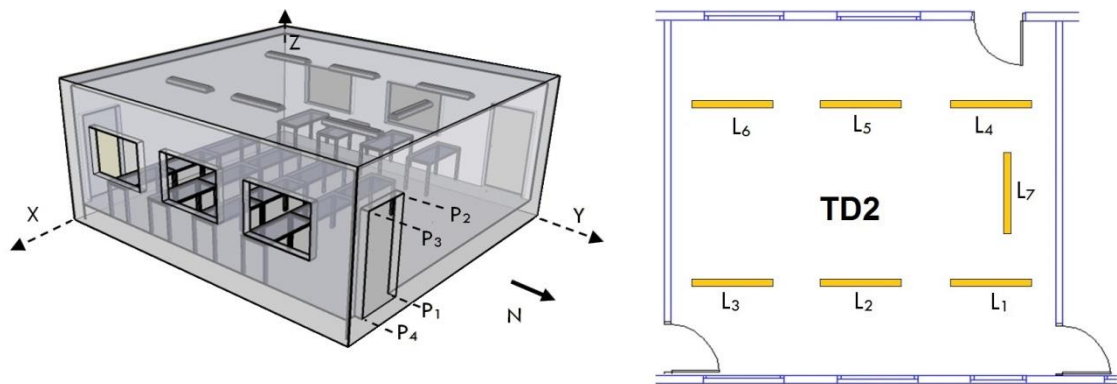

Fig.2. (a) Perspective; (b) Ground plan of the classroom

4.1. Daylight factor spatial distribution

The first issue raisedin this studywasthe need to have access to the luminous fluxonthe classroom's workplane.This distributionis stronglylinked to the positionand dimensions ofthe glazed openings. The most commonly usedfactor to characterizethisdistribution is theDF. The following figurethus shows the obtained values. As expected, the luminous fluxwas found to be higherclose to the windows, tending to decreasetoward the center of the room.
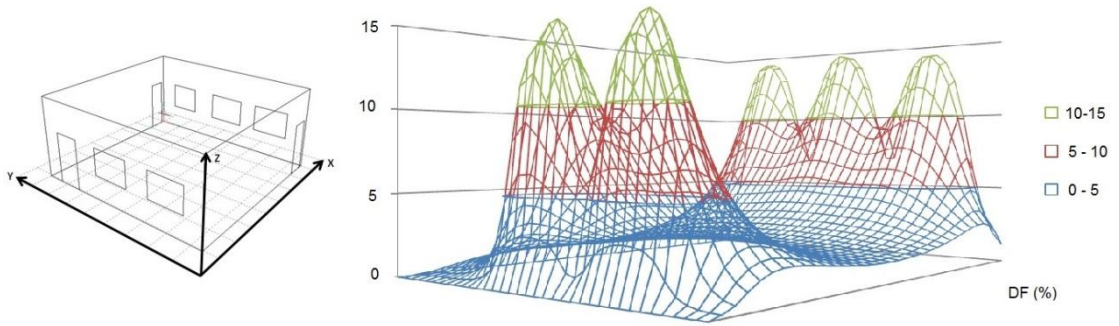
Fig. 3. (a) Perspective; (b) DF distribution in classroom

We obtainedan average value of4.34% (witha minimum of 0% on the perimeter ofthe surface of ourmeshand a maximum of 15.62% close to the western openings), which is slightlybelow theFrenchstandard.

4.2. Monthly average indoor illumination

The next stepof the studywasto examinetheoverall averageilluminanceof the roomthroughoutthe year.This providesan overview of thelighting autonomyof the studied room. Usingan hourly measured meteorological file anda model ofluminous efficiencypresented in [20], thevaluesshown in Figure 4were obtained.

The first observationis thatin a typicalyear,the averageilluminanceinsidethe classroomis approximately 1321lux.The room ismost illuminatedaround the month of November(1541 lux) and leastilluminatedaroundApril(1110lux).Overall,the room can beilluminated by naturallightwithout the needfor artificial lightingduring the day.
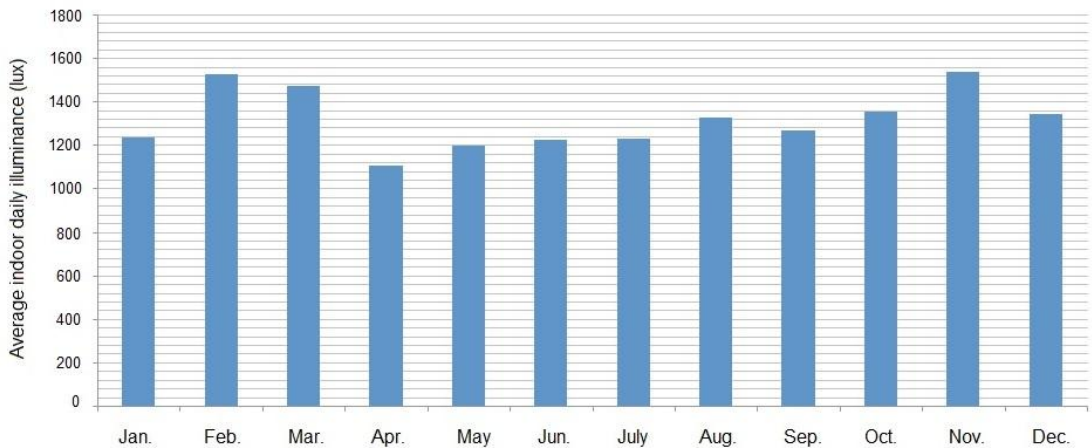

Fig. 4. Monthly average indoor illumination

4.3. Lighting autonomy

The curve in Figure 4 does not provide informationonthe *autonomy*durationof thelightin the room.Indeed,it is not possible to concludeduring whichpart of the daytheilluminationis sufficient in the room.To ascertain thetemporal availabilityconcerning the quantity ofinterior light, the evolution ofthe firstday of each monthwas observed.Figure 5 depicts theaveragecurves(inklux) available on themesh grid.
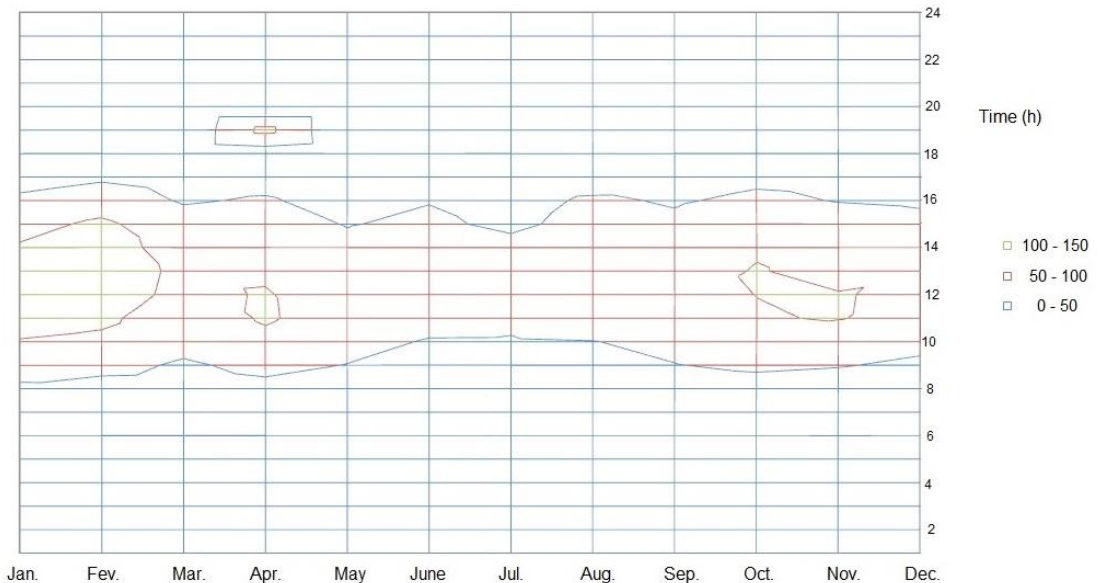

Fig.5. Average annual indoor illumination

Regular illumination was observedbetween 8 am and5pmthroughoutthe year.Themaximum value was2089lux(at noonon December 1). From the resultsobtained, wecan deduce thatthe averagefrequency with whichthe room can beilluminated—with naturallight—was90.8%. Only9.2% of the working hoursrequiredartificial lightingthroughout theyear, and thismostoften occurs between8 am and9amor4pmand5 pm.

5. Conclusion

Our goalof integrating amodelfor lightingcalculationwas reached, withdetailsonthe internal organizationprovidedin this article.Althoughspecific toour simulation software, these detailsare important for understanding thenecessarydata structuration to describea buildingin anysimulation code.

Although it is clear that this type of study can be performedusing other software (like E+), as in previous models (pollutants, airflow, etc.), we believe our own coding for this lighting model to be profitable in terms of its in-depth knowledge and flexibility, as it takes into account certain specificities or local practices.

The results of actual release were satisfactory in terms of their precision and comparability to much more powerful software. They allow us, in the philosophy of CODYRUN, to conduct specific software

development dedicated to research and professional audiences. In future research,we aim to explore theinnovativeintegration of specificcomponentsfor lighting(lightpipes, thermotropiclayers, etc.) and interfacingthe software withGoogle Sketchup® and OpenStudio®to improveitsusability among professionals.

References

[1] US DOE. EnergyPlusengineering reference: The reference to energy plus calculation.Technical report.US Department of Energy; 2009.

[2] Clarke, JA. *Energy simulation in building design*. Glasgow, UK: Adam Hilger Ltd; 1985.

[3]Marsh AJ, Calculating variations in the distribution of insolation over building surfaces.International Conference on Building Envelope Systems and Technologies (ICBEST). Sydney, Australia.2004.

[4] Klein, S. TRNSYS – A transient system simulation program. Engineering Experiment Station.Report 38–13.Madison: SolarEnergy Laboratory, University of Wisconsin; 2000.

[5] Boyer H, Chabriat JP, GrondinPerez B, Tourrand C, Brau J. Thermal building simulation and computer generation of nodal models. *Building and Environment* 1996;31:207–14.

[6] Boyer H, Garde F, Gatina JC, Brau J.A multi model approach of thermal building simulation for design and research purposes.*Energy and Buildings*1998;28:71–9.

[7] Boyer H, Lauret AP, Adelard L, Mara TA. Building ventilation: A pressure airflow model computer generation and elements of validation.*Energy and Buildings*1999;29:283–92.

[8] Soubdhan T, Mara TA,Boyer H, Younès A.Use of BESTEST procedure to improve a building thermal simulation program.In: World Renewable Energy Congress; Brighton, UK; 2000, p. 1800–1803, part. III.

[9] Lauret AJP, Mara TA, Boyer H, Adelard L, Garde F. A validation methodology aid for improving a thermal building model: How to account for diffuse radiation in a tropical climate.*Energy and Buildings*2001;33:711–18.

[10] Calogine D, Boyer H, Ndoumbe S, Rivière C, MiranvilleF. Identification of parameters in building concentration dispersion model.*Indoor Built Environment*2010;19(2):250–67.

[11] Fakra AH, Miranville F, Boyer H, Guichard S, Development of a new model to predict indoor daylighting: Integration in CODYRUN software and validation.*Energy Conversion and Management*2011;52:2724–34.

[12] Boyer H, Bojic M, Ennamiri H, Calogine D, Guichard S. Interroom radiative couplings through windows and large openings in buildings: Proposal of a simplified model.*JP Heat and Mass Transfer*2012;6(2):191–211.

[13] Lucas F, Adelard L, Garde F, Boyer H.Study of moisture in buildings for hot humid climates.*Energy and Buildings*2002;34(4):345–55.

[14] Boyer H, Gatina JC, Brau J, Pignolet F.Modelisation methods and data structuration induced for simulation codes. In: Proceedings of First Joint Conference of International Simulation Societies; ETH, Zurich; August 1994, p.729–33, 22–25.

[15] Peuportier B, Blanc-Sommeureux I.Simulation tool with its expert interface for the thermal design of multizone buildings. *Solar Energy*1990;8:109–20.

[16] Chartered Institution of Building Services Engineers. Window design. Application manual. London: Chartered Institution of Building Services Engineers; 1987.

[17] Siret D, Houpert S.A geometrical framework for solving sunlighting problems within CAD systems.*Energy and Buildings*2004;34(4):343–51.

[18] Foley JD, Van Dam A.*Fundamentals of interactive computer graphics*. Reading, MA: Addison-Wesley; 1982

[19] Maamari F, Fontoynont M, Adra N. Application of the CIE test cases to assess the accuracy of lighting computer programs.*Energy and Buildings* 2006;38:689–877.

[20]Fakra AH, Boyer H, Miranville F, Bigot D. A simple evaluation of global and diffuse luminous efficacy for all sky conditions in tropical and humid climate.*Renewable Energy*2011;36:298–306.

[21] Fakra AH, Intégration de modèles d'éclairage à un code de calcul en physique du bâtiment: Modélisation, validation et applications [dissertation].Saint Denis: Université de La Réunion;2009.