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Evolution of CODYRUN from thermal simulation to coupled thermal and daylight 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 software was originally used for the passive design of buildings, both for research and teaching purposes. In this context, the data treated were mainly concerned with volumes (zones), surfaces and thicknesses (walls and windows), materials, and systems, with the aim to determine temperatures, heat fluxes, energy consumed, air transfers, and so on.

The question thus arose as to the integration of indoor lighting conditions into the simulation. Hence, previous data structures had to be amended to incorporate the spatial positioning of entities (walls, windows, and artificial lighting sources) through vertices. A set of procedures was also developed for polygons as well as calculating natural and artificial lighting.

The results of this new daylighting module were then compared with other results of simulation codes and experimental cases both in artificial and natural environments. Excellent agreements were obtained, such as the values for luminous efficiencies in a 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 designs in 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, and daylighting. In the latter 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 analysis and resolves a coupled system describing thermal and airflow phenomena. Consequently, the ambient thermal comfort is estimated for buildings' systems. In these energy and comfort calculations, the precise location in space of a building's components should be noted, which is not usually helpful, with some models even requiring geometrical information, such as the height of openings [7] or solar masks [9].

At this step, the data treated were mainly concerned with volumes (zones), surfaces and thicknesses (walls and windows), materials, and systems, with the aim to determine temperatures, 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], and COMFIE [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 in Boyer et al. [5, 14].

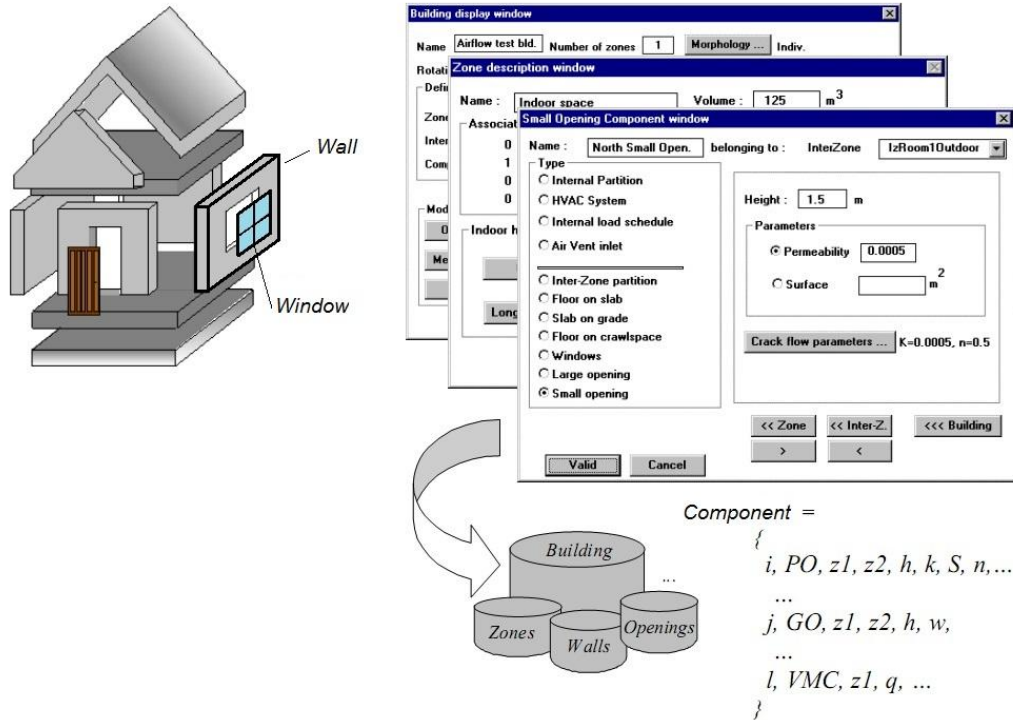


Fig. 1. (a) Component assembly of a building; (b) Associated windows and structures

2.2. Modified data structures

Taking into account the lighting calculations[21], the spatial positioning of the data relating to the walls, windows, apertures, and artificial illumination was required. Previous data structures describing these elements thus had to be expanded to incorporate the spatial positioning of the entities (walls, windows, and artificial lighting sources) through vertices. 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:

<i>T_Point</i>	<i>T_Polygon</i>	<i>T_Block</i>
{	{	{
float x, y, z;	T_Point Lst Pts[8];	short nTypeBlock;
}	short nSensDesc;	short nNbSommetsBlock;
	short nTypeSurf;	T_Poly Poly_1;
	}	T_Poly Poly_2;
		}

To ensure the spatial description of elements, this last data structure was incorporated into that of the components described in section 2.1. In the current version of CODYRUN, all of these coordinates are entered individually using the window descriptions. After a specific software development, these details

will soon be retrievable from Google Sketchup® and OpenStudio®. Then, new components for lighting were introduced for artificial lighting and light pipes.

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 plotted in space using its three coordinates (x, y, z). An example of the four points in a polygon (P1 to P4) is given in Figure 2a for an external opening.

Concerning an artificial lighting source, such as a light bulb, by allowing its assimilation to a point source, the coordinates of a single point must be defined (i.e., those of the point source).

2.3. Daylighting models

All available models require relative spatial positioning of the elements (floors, windows, openings, and light sources) to calculate the received light on each point in the working plane (or mesh).

The daylight factor (DF) classical method was used to calculate the diffuse illuminance for all of the mesh points. This method was elaborated by the British Building Research Establishment (BRE) and published by the Chartered Institution of Building Services Engineers (CIBSE) [16]. The diffuse light falling on one point in a room is 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. The direct illumination was obtained by projecting the edges of the glazing and the outer apertures eventually illuminated by direct solar radiation in order to calculate the indoor sunspot.

2.4. Geometrical considerations and polygons

A set of related C procedures relative to the geometry of planar polygons was incorporated into the code based on previous research [2, 17, 18]. It relates to, for example, the calculation of surface perimeters for polygons, the distance between a point and a plane, testing the inclusion of a point in a plane or polygon, or projections relating to shading calculations and the sunspot.

3. Validation of the model

Numerous validation tests of the CODYRUN code were successfully applied to the software. Apart from the daylighting model, the majority applied 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 of Maamari 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 exercise was conducted on a classroom in our university. The aim was to use the integrated model to enable students to understand natural and artificial lighting phenomena through various dynamic simulations (annual, monthly, and daily) in order to characterize the indoor lighting conditions and improve the visual comfort of the room. Some results from Fakra's study [21] are presented in the 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 total volume of 145 m³. 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 windows were 85% (given by the manufacturer), while the reflection coefficients of the doors were estimated at 70%.

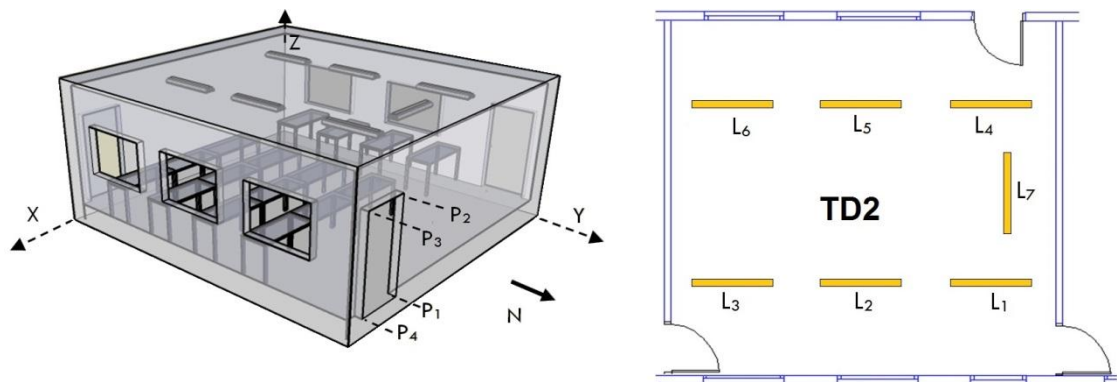


Fig.2. (a) Perspective; (b) Ground plan of the classroom

4.1. Daylight factor spatial distribution

The first issue raised in this study was the need to have access to the luminous flux on the classroom's workplane. This distribution is strongly linked to the position and dimensions of the glazed openings. The most commonly used factor to characterize this distribution is the DF. The following figure thus shows the obtained values. As expected, the luminous flux was found to be higher close to the windows, tending to decrease toward the center of the room.

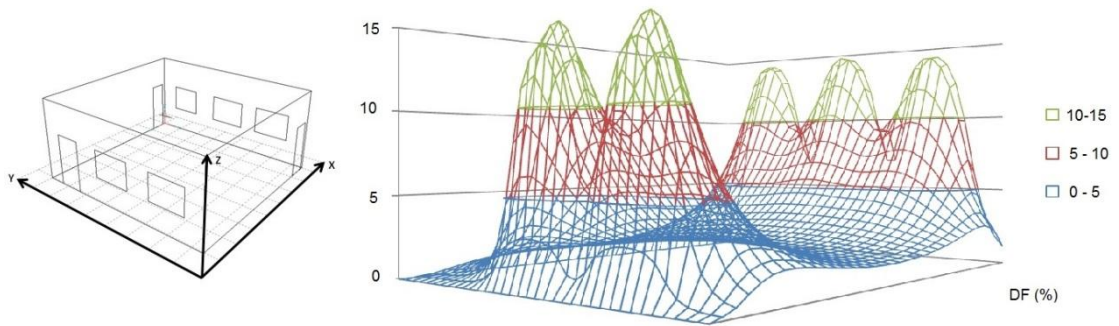


Fig. 3. (a) Perspective; (b) DF distribution in classroom

We obtained an average value of 4.34% (with a minimum of 0% on the perimeter of the surface of our mesh and a maximum of 15.62% close to the western openings), which is slightly below the French standard.

4.2. Monthly average indoor illumination

The next step of the study was to examine the overall average illuminance of the room throughout the year. This provides an overview of the lighting autonomy of the studied room. Using an hourly measured meteorological file and a model of luminous efficiency presented in [20], the values shown in Figure 4 were obtained.

The first observation is that in a typical year, the average illuminance inside the classroom is approximately 1321 lux. The room is most illuminated around the month of November (1541 lux) and least illuminated around April (1110 lux). Overall, the room can be illuminated by natural light without the need for artificial lighting during the day.



Fig. 4. Monthly average indoor illumination

4.3. Lighting autonomy

The curve in Figure 4 does not provide information on the *autonomy* duration of the light in the room. Indeed, it is not possible to conclude during which part of the day the illumination is sufficient in the room. To ascertain the temporal availability concerning the quantity of interior light, the evolution of the first day of each month was observed. Figure 5 depicts the average curves (in lux) available on the mesh grid.

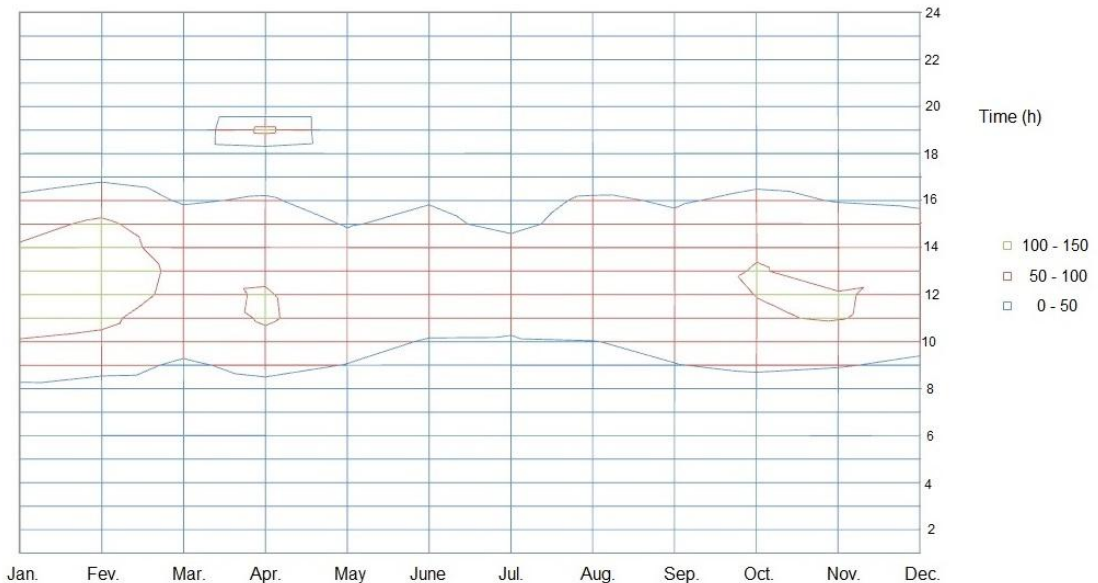


Fig.5. Average annual indoor illumination

Regular illumination was observed between 8 am and 5 pm throughout the year. The maximum value was 2089 lux (at noon on December 1). From the results obtained, we can deduce that the average frequency with which the room can be illuminated—with natural light—was 90.8%. Only 9.2% of the working hours required artificial lighting throughout the year, and this most often occurs between 8 am and 9 am or 4 pm and 5 pm.

5. Conclusion

Our goal of integrating a model for lighting calculation was reached, with details on the internal organization provided in this article. Although specific to our simulation software, these details are important for understanding the necessary data structuration to describe a building in any simulation code.

Although it is clear that this type of study can be performed using 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 the innovative integration of specific components for lighting (light pipes, thermotropic layers, etc.) and interfacing the software with Google Sketchup® and OpenStudio® to improve its usability among professionals.

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