VALIDATION OF THE CLIM2000 SOFTWARE PROGRAM BY USING ANALYTICAL VERIFICATION

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ABSTRACT

Up to now, within the framework of validation of the global building energy simulation software programme CLIM2000, we have not focused on analytical verification. Indeed, the scientific literature is not verbose on this subject due to the fact that only few thermal problems have analytical solutions. In the framework of International Energy Agency (IEA) Solar Heating And Cooling (SHAC) Task 22 (Building Energy Analysis Tools), a working document was established identifying and summarising analytical tests as verification and debugging tests for building energy analysis simulations. This paper presents the results obtained with CLIM2000 after implementing all these analytical tests.

1 - INTRODUCTION

The CLIM2000 software environment was developed by Electricity Applications in Residential and Commercial Buildings Branch in Research and Development Division of the French utility company EDF (Electricité De France). This software operational since June 1989, allows the behaviour of an entire building to be simulated. Its main objective is to produce economical studies, pertaining to energy balances over long periods as well as more detailed physical behaviour studies including stiff non-linear problems and varied dynamics. The building is described by means of a graphics editor in the form of a set of icons representing the models chosen by the user and taken from a library containing about 150 elementary models **[6]**.

In order to give end-users confidence in their simulated results, EDF has adopted a validation methodology for many years **[5]**, described as follows :

- examine the theoretical basis and algorithms used in the considered model,
- compare solution of analytical tests with simulated results,
- conduct tests of individual thermal processes using sensitivity analysis and uncertainty analysis,
- conduct comparison between softwares,
- conduct comparisons with high quality measured data and analyse the discrepancies between simulated and measured results by using tools for residual analysis based on spectral analysis **[7,8]**.

Up to now, we focused on all items listed above except on analytical verification. Indeed, the scientific literature is not verbose on this subject due to the fact that only few thermal problems have analytical solutions. This item is one of the points of interest treated in the framework of International Energy Agency (IEA) Solar Heating And Cooling (SHAC) Task 22 (Building Energy Analysis Tools). A working document has been established and summarises analytical test cases identified in the participating countries as verification and debugging tests for building energy analysis simulations. All these tests are based on simple physical phenomena where the exact solution is well known. They allow the code developers to verify and correct, if needed, their modelling because there is only one error source which can be responsible of discrepancies between simulated results and exact solution. This paper presents the CLIM2000 results.

2 - TESTS DESCRIPTION

2-a - Conduction tests

These basic tests allows users to evaluate the analytical solutions for ramp, step and sine wave step excitations. These changes are applied to external temperature and the evolution of internal temperature is observed. The initial temperature is 20°C for step and ramp tests and 0°C for the sine test. Three external condition changes in external temperature (Te) have been tested : **Ramp** : Te varies from 20°C to 70°C from t=0 to t=3600 s, and Te=70°C for t>3600s, **Step** : Te=70°C at t=0 s, **Sine** : Te=25*sin(2*pi*t/87300) for t>0 s. The total thickness of the wall is equal to 0.1m for step and ramp tests, and 0.2m for sine test. The thermal properties and the external film coefficient are the following ones : conductivity 0.14 W/m.K,, specific heat 2500 J/kg.K, density 500 kg/m^3, external coefficient 20 W/m².K. The exact solutions for ramp, step and sine tests are given in **[1]**, **[4]** and **[12]** .

2-b - Building level tests

These tests are based on the Wortman & al. report **[13]** (with the results of the different codes widely used in the USA), and the Bland and al. report **[2]**.

Each test consists of a building description, an analytical model, a weather file and a set of expected results for the test. The tests are divided into two groups : The 1st group contains tests which do not use mechanisms involving solar radiation and the 2nd group contains those which do : in the 1st group, the external perturbations of the building are just external temperature whereas in 2nd group, they are external temperature and solar fluxes. Depending on the tests, the analytical model is analytical expression of temperature, of fluxes, of transmittance, etc..

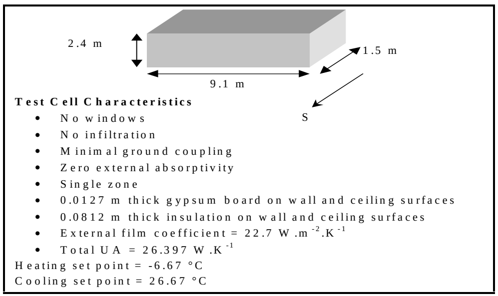


Figure 1: Building characteristics for building level tests

Description of the tests Group 1 : The base case for this 1st group is the Test #1, the Steady State Load and Temperature Rise and Decay Test. This test involves observing the responses of a building to step changes in ambient temperature. Theses responses include steady-state heating and cooling loads, and the decay or rise of interior air temperature. The building used is a “shoebox” as described in Figure 1 (all the characteristics, surface coefficients, conductivity, etc... are given in **[13]**). The weather file for test #1 was designed to drive the internal air temperature of the building using step changes in the external air temperature (Figure 2). All solar radiation values were set to zero **[12]**. The heating and cooling set points are respectively –6.67°C and 26.67°C. During the month of January, the building will experience a long period when heating is required with a constant outdoor temperature. The building UA for Group #1, and window U-Value for the other tests are easily calculated. Since the building heating q is predicted by the software program and the temperature difference between indoor and outdoor is known, the steady-state building UA can be calculated as follows :

$UA = q / (T_{indoor} – T_{outdoor})$

The windows U-values in tests #2 are obtained by subtracting the building UA and the external walls UA and by dividing the result by the window area. In this Group #1, dynamic behaviors have to checked for temperature rise (March) and temperature decay (June). To achieve that, the comparison between analytical solution and simulated results is based on normalized temperature which is $T_N(t) = \dfrac{T_w - T_\infty}{T_{w0} - T_\infty}$, where $T_N(t)$ is the normalized temperature, T_w room air temperature, T_∞ external temperature and T_{w0} initial room air temperature.

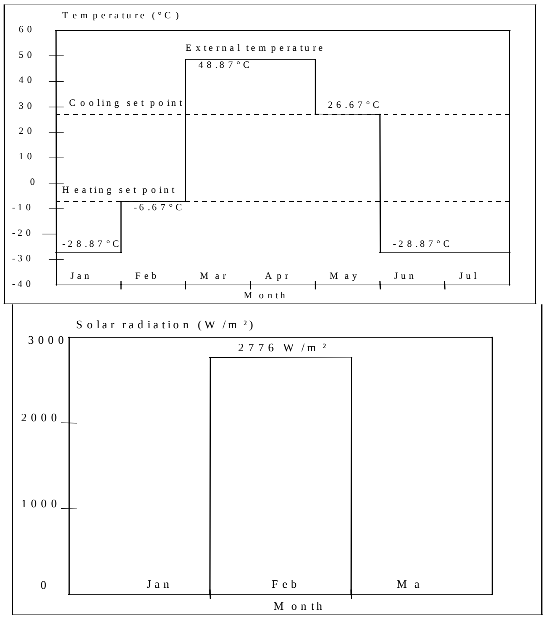


Figure 2: Weather conditions for building level tests

Description of the tests Group 2 : The weather file for this 2nd group is the Test #2, which was designed to drive the internal air temperature to step changes in solar radiation (Figure 2). The horizontal solar radiation was taken as the driving function, while direct radiation was set to zero. Thus, the codes will only detect diffuse radiation incident upon the glazing, eliminating the directional effects. The ambient temperature is set to 26.67°C. By choosing a cooling set point equal to external air temperature, this allows the transmittance of the glazing to be calculated. The transmittance value is obtained by dividing the transmitted diffuse radiation flux by incident diffuse radiation flux on a vertical surface. In this Group #2, it is also necessary to check the thermal response of the thermal mass to solar radiation. This is based also on normalized temperature which is $T_{NR} = \dfrac{T_i}{Q} - T_{NR0}$ where TNR(t) is the normalized temperature, T_i is the internal temperature, Q is the incoming radiant flux and T_{NR0} is the initial normalized temperature. Note that T_{NR} is not really a temperature because the units are m².°C/W, but this is the name given by the authors **[13]**, so we kept it. The analytical solution of temperature is given **[13]**. It comes from the FOURIER equation where initial conditions and boundary conditions are applied. Equation is too long to be incorporated here. For more details, the reader is invited to refer to **[13]**. The building level tests are described in Table 1.

Table 1: Description of the building level tests

Test #	Building model	Purpose and description
1	Test #1 : Shoebox	Tests steady-state load/temperature rise and decay. Shoebox with 2 insulation levels to produce overall UA of 26.40W.K^{-1}.
2	Glazing	Determines UA of glazings. Shoebox with 11.18 m² of glazing, 1, 2, or 3 panes of glass.
3	Conservation	Checks building responses caused by changes in overall UA. Shoebox with insulation level to produce overall UAs of 10.56 and 79.19 W.K^{-1}.
4	Aperture	Checks building responses caused by changes in window aperture. Shoebox with double glazing and apertures of 3.72 and 7.43 m².
5	Infiltration	Checks building responses caused by variations in infiltration rates. Shoebox with infiltration rates of 0.5, 1, 1.5, 2, 3 and 5 air changes per hour.
6	High mass	Checks building responses caused by variations in thermal mass. Shoebox with 0.18m concrete on walls, low-heat-loss ceiling, and insulation to yield a total UA of 26.40 W.K^{-1}.
7	Test #2	Tests window transmissivity for double glazing and temperature response of thermal mass caused by solar radiation. Glazing model with infinite thermal resistance exterior to the thermal mass on all walls and ceiling. Aperture of 1 m².
8	Glazing charging	Tests window transmissivity for single and triple glazings. Aperture of 1 m².
9	Aperture charging	Tests window transmissivity for double glazing as aperture is changed. Apertures of 3.72 and 7.43 m².
10	High-mass charging	Checks temperature response of thermal mass caused by solar radiation.

2-c - Long wave radiation tests

These tests are described in the references **[3]**, **[9]**, **[11]** and **[12]**. The basic assumptions in the treatment of long-wave radiative heat exchange in a room are the following ones : the radiative properties of each surface are uniform ; temperature and heat flux are uniform over each surface ; the radiative flux is uniformly distributed ; the surfaces are opaque ; the air does not participate in the exchange. All the tests are steady-state. Exact view factors are calculated analytically. In **test 1**, the configuration to be used is the configuration #1 (Figure 3). All surface emissivities are set to 0.9, the temperature of surfaces #2 to #6 is equal to 20°C and the heat flux on surface #1 has to be calculated for four different temperature of surface #1 (-15°C, 10°C, 30°C et 60°C) ; the tests are called 1A, 1B, 1C and 1D respectively. **In test 2**, the same geometrical configuration is investigated for a single temperature distribution, surface #1 : 10°C, surfaces #2 to #6 : 20°C. The value of emissivities are : 0.9 for surfaces #2 to #6. The heat fluxes on surfaces #1 and #2 have to be calculated for various values of emissivity on surface #1 :0.1, 0.5 and 0.8 ; the tests are called 2A, 2B, and 2C respectively. **In test 3**, for constant temperatures (surface #1 : 10°C, surfaces #2 to #6 : 20°C and emissivities (0.9 for all surfaces), the energy exchanges for the four geometrical configurations (Figure 3) have to be determined. The tests are called : 3A, 3B, 3C and 3D respectively. Exact view factors are calculated for geometries 1 and 4 by a given formulae **[12]** . These last tests are called 3E and 3F respectively.

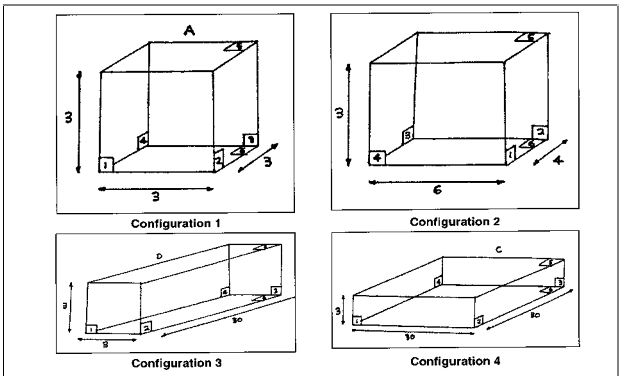


Figure 3: Configurations 1, 2, 3 and 4 for long wave radiation tests (dimensions in meters).

2-d - Shading tests

These tests are described in **[10][12]**.They allow the users to verify analytically the effect of very simple shading devices that should normally be modeled in the building energy analysis tools. For each configuration, the manual gives : the geometrical description of the shading, the analytical expression of the shadow, and a FORTRAN routine listing translating the analytical expression, which gives the sunlit fraction of the total window area as a function of the relative solar position and the geometrical parameters of the typology. The shading devices studied are the following ones : set-back window, overhang of infinite length, overhang of finite length, side fin and awning. The geometrical description of them is given on Figure 4. It is requested to calculate the shading effect of each device i.e. to calculate the sunlit fraction of window. The algorithms for calculating the analytical solution of each shading device associated to geometrical signification, are described in **[10][12]**. The expressions are too long to be reproduced here. Nevertheless, they are based on the geometrical projection of each corner of shading devices onto the window plane.

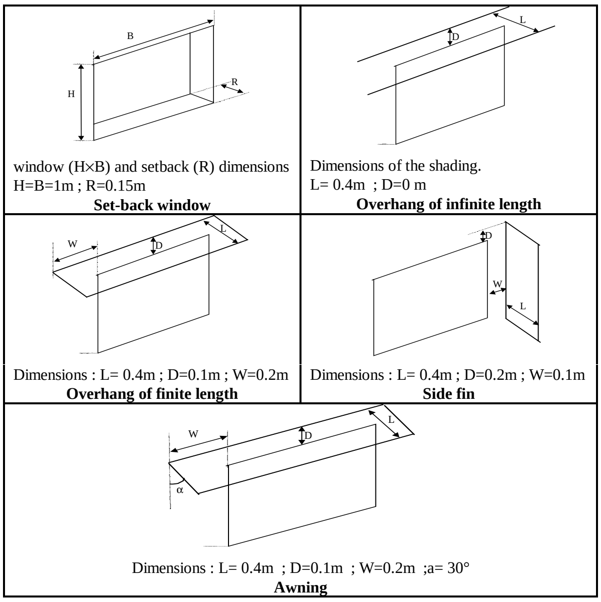


Figure 4: Geometrical description of shading devices

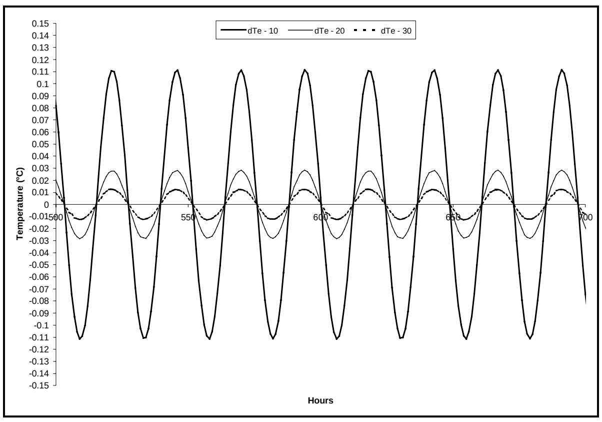
3 - RESULTS

3-a - Conduction tests

The elementary models available into CLIM2000 allowing the calculations of conduction heat transfer are based on one-dimensional finite differences method (FDM) **[6]**. The calculations are carried out by using a commercial solver called ESACAP which is a general solver for non-linear dynamic systems which uses backward-differentiation formulas (BDF) with variable step and order (from 1 to 6). For each external temperature condition, three types of discretization (10, 20 and 30 thermal mass nodes – according to the FDM used into CLIM2000- of equal thickness) for the wall were tested in order to see the number of nodes impact. We only present the results obtained with 30 nodes.

The results of **ramp and step tests** are given in Table 2 and Table 3 resp.. As we can see in these tables, the CLIM2000 results are in a very good agreement with the exact solution. This result can be interesting when using the software to study precisely the impact of a quick modification of external conditions on internal surface temperatures of a house for instance. Of course, it is not necessary to have such precise discretization when calculating the global energy consumption of a building during a large period of time.

The results related to **sine tests** are given in Figure 5. The exact solution of surface temperature response given in **[2, 12]** (internal and external) is as follows : Ts=α*sin(ωt+ϕ), where α is amplitude, ω is frequency of the excitation and ϕ phase lag. Then, for internal surface temperature, the values are : α=1.224330376521°C ; ϕ=-0.5538867616007 rads. For external surface temperature, the values are : α= 22.08127776735 °C ; ϕ=-0.1110783808153 rads. Equations are too long to be incorporated here. For more details, please refer to **[1]**.



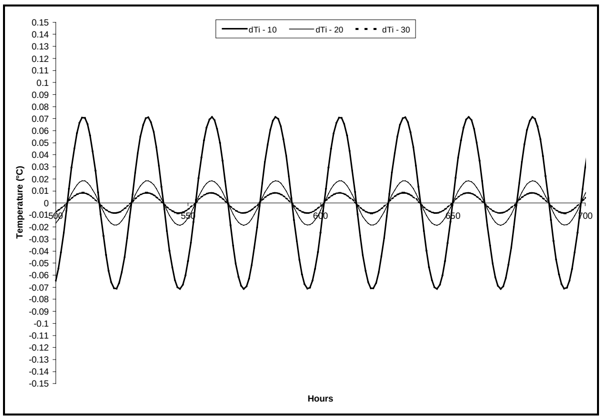


Figure 5: Differences between CLIM2000 results and exact solution for external (dTe) and internal surfaces (dTi)

For these tests, the analytical results are given for an established temperature, excluding the preconditioning period due to the initial state of the system. Then, the simulations have to be performed over a long period. It is not possible to compare the results during the preconditioning period, and the comparison is made after this stage. The results presented in Figure 5 show the differences between CLIM2000 results and analytical solution for 3 kinds of discretization (10, 20 and 30 nodes). For external temperature, the simulation and the analytical solution are very close together all over the simulation. For the internal temperature, the preconditioning period due to the initial state of the system appears over about the 10 first periods. After this, the results obtained with CLIM2000 and the exact solution are very close together all over the remaining period of simulation. Once again, the results show that the difference between analytical solution and simulated results is all the more high since the number of nodes is low.

From these tests, we can conclude that the CLIM2000 elementary models used for conduction problems are well implemented and are precise.

3-b - Building level tests

The results of these tests are given in Table 4, and we also added the results of SUNCAT, DOE2.1 and DEROBIII **[13]**.

For each test of Group 1, all the codes show reasonable agreement with the expected solutions. DEROB shows UA-values much higher than the others codes. Upon investigation, a loss mechanism proportional to the building perimeter length was discovered. We can note the excellent results of CLIM2000.

Table 2: CLIM2000 results for RAMP test, 30 nodes

RAMP FUNCTION : 30 nodes

Tsi : Internal wall surface temperature ; Tse : External wall surface temperature : Tb : excitation

F_1 : heat flux through external wall surface ; dTsi= Tsi analytical - Tsi simulated ; dTe = Tse analytical - Tse simulated

Hour	Tsi simulated	Tsi analytical	DTsi	Tse simulated	Tse analytical	dTse	Tb	F_1
0	20.0000	20.0000	0.0000	20.0000	20.0000	0.0000	20.00	0.0000
1	20.0030	20.0024	-0.0006	55.3050	55.2754	-0.0296	70.00	-293.9100
2	20.3160	20.3081	-0.0079	62.1580	62.1646	0.0066	70.00	-156.8500
3	21.8920	21.8784	-0.0136	63.8900	63.8937	0.0037	70.00	-122.2000
4	24.5940	24.5801	-0.0139	64.8200	64.8222	0.0022	70.00	-103.6000
5	27.7630	27.7509	-0.0121	65.4360	65.4375	0.0015	70.00	-91.2790
6	30.9980	30.9883	-0.0097	65.9000	65.9006	0.0006	70.00	-82.0080
7	34.1160	34.1084	-0.0076	66.2790	66.2797	0.0007	70.00	-74.4180
8	37.0450	37.0384	-0.0066	66.6060	66.6067	0.0007	70.00	-67.8750
9	39.7620	39.7562	-0.0058	66.8970	66.8971	0.0001	70.00	-62.0650
10	42.2670	42.2623	-0.0047	67.1590	67.1591	0.0001	70.00	-56.8250
20	58.3640	58.3665	0.0025	68.8100	68.8105	0.0005	70.00	-23.8020
30	65.1190	65.1229	0.0039	69.5010	69.5013	0.0003	70.00	-9.9850
40	67.9520	67.9554	0.0034	69.7910	69.7909	-0.0001	70.00	-4.1887
50	69.1410	69.1428	0.0018	69.9120	69.9123	0.0003	70.00	-1.7572
60	69.6400	69.6406	0.0006	69.9630	69.9632	0.0002	70.00	-0.7372
70	69.8490	69.8493	0.0003	69.9850	69.9845	-0.0005	70.00	-0.3092
80	69.9370	69.9368	-0.0002	69.9940	69.9935	-0.0005	70.00	-0.1297
90	69.9730	69.9735	0.0005	69.9970	69.9972	0.0002	70.00	-0.0544
100	69.9890	69.9889	-0.0001	69.9990	69.9988	-0.0002	70.00	-0.0228

Measure of error based on hours 1 to 9	dTsi	dTse
Mean difference (°C)	-0.0086	-0.0015
Mean abs. diff (°C)	0.0086	0.0051
Root mean square (°C)	0.0095	0.0102
Maximum abs. difference (°C)	0.0139	0.0296
Measure of error based on hours 10 to 100	dTsi	dTse
Mean difference (°C)	0.0008	0.0000
Mean abs. diff (°C)	0.0018	0.0003
Root mean square (°C)	0.0024	0.0003
Maximum abs. difference (°C)	0.0047	0.0005

Table 3: CLIM2000 results for STEP test, 30 nodes

STEP FUNCTION : 30 nodes

Tsi : Internal wall surface temperature ; Tse : External wall surface temperature : Tb : excitation

F_1 : heat flux through external wall surface ; dTsi= Tsi analytical - Tsi simulated ; dTe = Tse analytical - Tse simulated

Hour	Tsi simulated (°C)	Tsi analytical (°C)	dTsi (°C)	Tse simulated (°C)	Tse analytical (°C)	dTse (°C)	Tb (°C)	F_1 (W/m²)
0	20.0000	20.0000	0.0000	20.0000	20.0000	0.0000	20.00	0.0000
1	20.0240	20.0219	-0.0021	60.6680	60.6783	0.0103	70.00	-186.6500
2	20.8590	20.8465	-0.0125	63.2360	63.2407	0.0047	70.00	-135.2800
3	23.1160	23.1022	-0.0138	64.4290	64.4320	0.0030	70.00	-111.4100
4	26.1430	26.1304	-0.0126	65.1620	65.1639	0.0019	70.00	-96.7540
5	29.3900	29.3789	-0.0111	65.6860	65.6869	0.0009	70.00	-86.2820
6	32.5850	32.5764	-0.0086	66.1000	66.1007	0.0007	70.00	-77.9990
7	35.6160	35.6080	-0.0080	66.4500	66.4503	0.0003	70.00	-71.0040
8	38.4400	38.4331	-0.0069	66.7570	66.7572	0.0002	70.00	-64.8630
9	41.0500	41.0439	-0.0061	67.0320	67.0324	0.0004	70.00	-59.3580
10	43.4520	43.4469	-0.0051	67.2820	67.2818	-0.0002	70.00	-54.3690
20	58.8620	58.8649	0.0029	68.8610	68.8614	0.0004	70.00	-22.7830
30	65.3280	65.3318	0.0038	69.5220	69.5226	0.0006	70.00	-9.5574
40	68.0400	68.0430	0.0030	69.8000	69.7999	-0.0001	70.00	-4.0094
50	69.1780	69.1795	0.0015	69.9160	69.9161	0.0001	70.00	-1.6819
60	69.6550	69.6560	0.0010	69.9650	69.9648	-0.0002	70.00	-0.7056
70	69.8550	69.8558	0.0008	69.9850	69.9852	0.0002	70.00	-0.2960
80	69.9390	69.9395	0.0005	69.9940	69.9938	-0.0002	70.00	-0.1242
90	69.9750	69.9746	-0.0004	69.9970	69.9974	0.0004	70.00	-0.0521
100	69.9890	69.9893	0.0003	69.9990	69.9989	-0.0001	70.00	-0.0219

Measure of error based on hours 1 to 9	dTsi	dTse
Mean difference (°C)	-0.0091	0.0025
Mean abs. diff (°C)	0.0091	0.0025
Root mean square (°C)	0.0098	0.0040
Maximum abs. difference (°C)	0.0138	0.0103
Measure of error based on hours 10 to 100	dTsi	dTse
Mean difference (°C)	0.0008	0.0001
Mean abs. diff (°C)	0.0019	0.0002
Root mean square (°C)	0.0025	0.0003
Maximum abs. difference (°C)	0.0051	0.0006

Table 4: Results of the building level tests

Test	Description			SUNCAT	DOE 2.1	DEROB III	CLIM2000 infrared rad not considered	CLIM2000 infrared rad consid.	Analytical
	UA is in W/K U-values in W/m².K Incident and transmitted radiations in W/m².								
	Group 1								
1.1	**Test 1** : Building UA		LOW	26.71	26.40	27.08	26.40		26.4
1.2			MID				26.41		
1.3			HIGH				26.39		
2.1	**Glazing** : Building UA	Single G		89.43	68.84	77.82	71.84	76.64	89.70
2.2			Double G	60.20	51.74	57.81	54.89	57.68	59.92
2.3			Triple G	48.16	43.50	48.60	46.53	48.47	47.88
2.1	Window U-value		Single G	6.07	4.20	4.94	4.47	4.90	6.07
2.2			Double G	3.40	2.67	3.18	2.95	3.20	3.40
2.3			Triple G	2.33	1.93	2.33	2.20	2.38	2.33
3.1	**Aperture** : Building UA	3.72m² of DG		37.85	34.45	37.27	35.88	36.81	37.59
3.2			7.43 m² of DG	49.05	43.26	47.62	45.33	47.19	48.78
4.1	**Conservation** :	UA=10.56		10.61	10.51	11.09	10.55		10.56
4.2		UA=79.19		82.09	79.67	82.46	79.20		79.19
5.1	**Infiltration** : Building UA	0.50 ACH		32.47	32.53	32.79	31.97		32.1
5.2			1.0 ACH	38.22	38.86	38.49	37.54		37.8
5.3			1.5 ACH	43.98	45.14	44.19	43.11		43.5
5.4			2.0 ACH	49.73	51.37	49.89	48.68		49.2
5.5			3.0 ACH	61.24	63.83	61.29	59.81		60.6
5.6			5.0 ACH	84.26	88.85	84.10	82.09		83.4
6	**High Mass**		see 2.1.3	26.40	26.34	27.06	26.39		26.40
	Group 2								
	Test 2								
7	Incident radiation	S=1m²	Double G	1385.5	1664.5	1525.8	1664.4		
	Transmitted radiation			904.80	1131.40	958.7	1125.1		
	Transmittivity			0.65	0.68	0.63	0.68		
	Glazing changing								
8.1	Incident radiation	S=1m²	Single G	1385.5	1664.50	1525.80	1664.4		
	Transmitted radiation			1081.3	1329.7	1215.0	1339.80		
	Transmittivity			0.78	0.80	0.8	0.80		
8.2	Incident radiation	S=1m²	Triple G	1385.5	1664.50	1525.8	1664.4		
	Transmitted radiation			770.6	993.0	752.2	938.72		
	Transmittivity			0.56	0.6	0.49	0.56		
	Aperture changing								
9.1	Incident radiation	S=3.72 m²	Double G	1385.5	1664.5	1525.8	1664.40		
	Transmitted radiation			904.8	1131.40	958.70	1125.13		
	Transmittivity			0.65	0.68	0.63	0.68		
9.2	Incident radiation	S=7.43m²	Double G	1385.5	1664.5	1525.8	1664.4		
	Transmitted radiation			904.80	1131.4	958.7	1125.12		
	Transmittivity			0.65	0.68	0.63	0.68		
	High mass								
10	Incident radiation	S=1m²	Double G	1385.5	1664.5	1525.80	1664.4		
	Transmitted radiation			904.8	1131.40	958.7	1125.1		
	Transmittivity			0.65	0.68	0.63	0.68		

Table 5: CLIM2000 results vs analytical solution-Building level tests-Different inertia

Low mass			Mid-mass			High mass		
Time	TN simulated	TN analytical	Time	TN simulated	TN analytical	Time	TN simulated	TN analytical
0	1	1	0	1	1	0	1	1
1	0.914	0.914	4	0.96	096	10	0.942	0.942
2	0.835	0.835	8	0.922	0.922	20	0.888	0.889
3	0.762	0.763	12	0.885	0.886	30	0.837	0.838
4	0.696	0.697	16	0.850	0.851	40	0.789	0.791
5	0.636	0.637	20	0.816	0.817	50	0.743	0.745
6	0.581	0.582	24	0.784	0.785	60	0.701	0.703
7	0.531	0.532	28	0.753	0.754	70	0.660	0.663
8	0.485	0.486	32	0.723	0.724	80	0.622	0.625
			36	0.694	0.695			
			40	0.667	0.668			

We used two different modelling for glazing : 1) IR not considered i.e. emissivity set to zero and use of global surface coefficients ; 2) IR considered i.e. use of real value of emissivity and use of convective film coefficients. For Glazing tests, CLIM2000 for which the infrared effect was checked, can be compared to the results of DOE2.1 or DEROB : IR not considered: compare CLIM2000 (a) to DOE2.1, which are in good agreement ; IR considered : compare CLIM2000 (b) to DEROB, which are very close together. The glazing properties taken into account for CLIM2000 are different of those given in the analytical results (it was not provided in the test definitions). Our overall glazing properties are closer to the properties used for DOE2.1 and DEROB than for those used in SUNCAT or analytical results. Note that taking into account IR radiation implies a rise of the U-value of the glazing in the case when the internal temperature is greater than external temperature. For dynamic tests, the CLIM2000 results are compared to the analytical solution in Table 5. The results are excellent and quasi-equivalent to the analytical solution and there is a symmetry between the rise and the temperature decay. For conservation tests, all the codes produce results that are close (within 6% steady-state UA) to the solution for both levels of insulation. For infiltration tests, all the programs results show, as expected, a linear relationship between building heat losses and infiltration rates. The slope of CLIM2000 is equal to 1.224 kJ.m^{-3}.K^{-1}, close to the analytical value.

Group 2 results : CLIM2000 results must be compared to the other program results taking into account theses points : as for DOE2.1, the ground reflectance in CLIM2000 was set to 0.2. It was set to 0 for SUNCAT, and set to 0.1 for DEROB; for DEROB and DOE2.1, the transmitted radiation is the sum of the radiation energy absorbed by the glass + the infrared emissions of glazing ; CLIM2000 and SUNCAT transmitted radiation is the solar radiation transmitted through the glazing. For dynamic tests (not presented), CLIM2000 results are close to exact solution, the average value of the difference between CLIM2000 results and analytical solution is less than 4.8%. All the results of CLIM2000 are consistent with the modelling hypotheses and the above discussion.

3-c - Long wave radiation tests

For these tests, in order to calculate heat fluxes on each surface, we used specific models available in CLIM2000 library based on the radiosity method **[6]**.

Tests 1 : CLIM2000 results are given in Table 6. We can note the very good agreement with exact solution.

Table 6: Results of tests 1A, 1B, 1C & 1D

Results : Heat flux on Surface 1 (Watts)				
Temperature of Surface 1 (°C)	-15	10	30	60
Test Label	1A	1B	1C	1D
Exact solution	**1325.7**	**431.0**	**-477.6**	**-2221.6**
CLIM2000	1325.5	431.0	-477.6	-2221.4

Test 2 : : CLIM2000 results are given in Table 7. We can note the very good agreement with exact solution.

Table 7: Results for Tests 2A, 2B and 2C

	Results for Tests 2A, 2B and 2C – Heat fluxes on Surfaces 1 & 2					
	Heat flux on Surface 1 (Watts)			Heat flux on Surface 2 (Watts)		
Test Label	2A	2B	2C	2A	2B	2C
Exact	**48.7**	**241.6**	**384.0**	**9.8**	**48.4**	**76.9**
CLIM2000	48.7	241.5	384.0	9.8	48.4	76.9

Test 3 : CLIM20000 results are given in Tables 8, 9, 10 and 11. The results are given in Tables 12 and 13 for view factors. The absolute differences for the view factors between the analytical values and the calculated values are less than 10^{-4}.

Table 8: Results for Test 3A

	Tests 3A - Configuration 1 - Heat flux on Surfaces (Watts)				
	Surface 1	Surfaces 2 and 4	Surface 3	Surfaces 5 and 6	Energy balance
Exact	431	-86.3	-86.2	-86.3	-0.4
CLIM2000	431	-86.3	-86.2	-86.3	-0.4

Table 9: Results for Test 3B

	Results for Test 3B - Configuration 2 - Heat flux on Surfaces (Watts)				
	Surface 1	Surfaces 2 and 4	Surface 3	Surfaces 5 and 6	Energy balance
Exact	**579**	**-113.5**	**-52.9**	**-149.4**	**0.4**
CLIM2000	578.9	-113.5	-52.9	-149.4	0.4

Table 10: Results for Test 3C

	Geometry c - Heat flux on Surfaces (Watts)				
	Surface 1	Surfaces 2 and 4	Surface 3	Surfaces 5 and 6	Energy balance
Exact	**4377**	**-2.6.2**	**-118.4**	**-1898.2**	**-10.1**
CLIM2000	4377	-235.8	-117.9	-1896.6	-5.6

Table 11: Results for Test 3D

	Configuration 4 - Heat flux on Surfaces (Watts)				
	Surface 1	Surfaces 2 and 4	Surface 3	Surfaces 5 and 6	Energy balance
Exact	**438.6**	**-109.1**	**-2.3**	**-109.1**	**0**
CLIM2000	438.6	-109	-2.3	-109	0.3

These tests show out also the excellent results of CLIM2000 in terms of heat fluxes (difference less than 0.5%). The reason of these excellent results are due to the fact that the algorithms used into CLIM2000 are the same than the real theory of radiation.

3-d - Shading tests

For these tests, we used specific elementary models available in CLIM2000 models library allowing the real calculation of sunlit fraction [**6**]. The technique used into CLIM2000 consists in calculating the geometrical projection of each corner of the shading devices onto the window plane. The results are given in Table 14. We can see that all the results are quite equal to the analytical solutions. This result is normal because the way to calculate the sunlit factor is the same into CLIM2000 and into the analytical solution. Nevertheless, this test proves that the implementation of the theory into CLIM2000 is correct.

CONCLUSION

This paper presents the validation procedure used at EDF for CLIM2000 software program. Basically, it is based on three different items : analytical verification, inter-model comparison and empirical validation. We have focused on the application analytical tests on CLIM2000. The CLIM2000 results are excellent for all test cases. The others conclusions are the following ones : analytical tests have to be applied by each code developers ; they are easy to implement, they are not time consuming ; they provide a definitive advice on the capability of the considered software program to model certain physical phenomena. and they can avoid big errors during development phases of software program. They represent the basic step in the validation procedure of a software.

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Table 12: Results for Test 3 E - View factors - Configuration 1

View factors - Configuration 1												
	Surfaces											
Surfaces	1 simul	1 analyt.	2 simul	2 analyt	3 simul	3 analyt	4 simul	4 analyt	5 simul	5 analyt	6 simul	6 analyt
1	0	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2	0.2	0.2	0	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
3	0.2	0.2	0.2	0.2	0	0	0.2	0.2	0.2	0.2	0.2	0.2
4	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0.2	0.2	0.2	0.2
5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0.2	0.2
6	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0

Table 13: Results for Test-3F - View factors - Configuration 4

View factors -Configuration 4												
	Surfaces											
Surfaces	1 simul	1 analyt.	2 simul	2 analyt	3 simul	3 analyt	4 simul	4 analyt	5 simul	5 analyt	6 simul	6 analyt
1	0	0	0.249	0.249	0.03	0.03	0.249	0.249	0.249	0.249	0.249	0.249
2	0.025	0.025	0	0	0.025	0.025	0.386	0.386	0.282	0.282	0.282	0.282
3	0.003	0.003	0.249	0.249	0	0	0.249	0.249	0.249	0.249	0.249	0.249
4	0.025	0.025	0.386	0.386	0.025	0.025	0	0	0.282	0.282	0.282	0.282
5	0.025	0.025	0.282	0.282	0.025	0.025	0.282	0.282	0	0	0.386	0.386
6	0.025	0.025	0.282	0.282	0.025	0.025	0.282	0.282	0.386	0.386	0	0

Table 14: CLIM2000 results for shading tests - Sunlit fraction

	Set-back window		Overhang of infinite length		Overhang of finite length		Side fin		Awning	
Time (s)	Simulation	Analytical solution	Simulation	Analytical solution.	Simulation	Analytical solution	Simulation	Analytical sol.	Simulation	Analytical sol.
25200	0.	0.	0.	0.	0.	0.	0.	0.	0.	
28800	0.11564	0.11564	0.	0.	0.57553	0.57552	0.25999	0.25999	0.35481	0.35480
32400	0.44087	0.44087	0.04881	0.04881	0.38034	0.38035	0.50976	0.50975	0.32522	0.32523
36000	0.59031	0.59031	0.20417	0.20417	0.35092	0.35092	0.77144	0.77143	0.35591	0.35590
39600	0.67784	0.67784	0.26323	0.26324	0.36323	0.36324	0.95765	0.95764	0.38521	0.38521
43200	0.71752	0.71752	0.27516	0.27516	0.37516	0.37516	1.	1.	0.39117	0.39117
46800	0.64865	0.64865	0.24747	0.24747	0.35222	0.35222	1.	1.	0.37733	0.37733
50400	0.54381	0.54380	0.16157	0.16157	0.35548	0.35548	1.	1.	0.34234	0.34234
54000	0.34854	0.34853	0.	0.	0.42999	0.42999	1.	1.	0.31872	0.31872
57600	0.	0.	0.	0.	0.65000	0.65001	1.	1.	0.50704	0.50704