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Indoor Air Quality and the Probability of Mould Occurrence on Insulated Dwellings Walls in Southern Brazil

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ABSTRACT

European Directives Have Required A Higher Energy Efficiency In Buildings And, For This Reason, Some Countries Have Adopted A More Insulated Model That Provides A Minimum Heat Exchanges With The External Environment, Thus Keeping The Internal Temperature With Low Oscillation And Ensuring A Lower Energy Consumption For Air Conditioning. The Applicability Of This Model Has Been Studied And Extended To Other Warmer Countries, Including Brazil. This Paper Presents The Results Verified, By Computational Simulation, Of The Use Of Thermal Insulation On The External Wall Façade In A Single-Family Dwelling In The Southern Brazil. There Were Good Results Regarding Indoor Thermal Conditioning, However, Due To The Climatic Characteristics, The Moist Content Was Above 80% For More Than 6 Hours Between 40% And 50% From Year Hours, Bringing Great Possibility Of Mould Formation And Reducing Indoor Air Quality.
Keywords-Energy Efficiency, Computational Simulation, Thermal Insulation, Humidity

I. INTRODUCTION

As An Attempt To Reduce Energy Consumption Related With Thermal Conditioning Of Buildings, European Directives Have Demanded Increasing Higher Thermal Insulation On Façades. A Model Of High Insulated Construction Provides A Minimum Of Heat Exchanges With The External Environment, Maintaining Indoor Temperature With Low Oscillations And Ensuring Less Energy Consumption For Air Conditioning. Although This Model Ensures High Energy Efficiency, Some Authors Have Pointed Out The Occurrence Of Indoor Overheating During Summer, Even In Predominantly Cold Climates, And Also Low Indoor Air Quality [1,2]. Some Studies Have Indicated The Necessity To Review This Model [3,4], While Others Have Been Tested Its Applicability In Tropical Countries, Including Brazil [5,6,7].

According To Authors [8,9], The Practice Of Increasing Thermal Insulation, Makes More Airtight The Building Envelope And Bringing Greater Energy Efficiency, Has Also Created Conditions To A Rapid Growth Of Mould, With Prejudice To The Indoor Air Quality. Although Human Health Is Not Affected By High Levels Of Humidity, Health Effects Are Related To The Growth And Propagation Of Biotic Agents [10], Increasing The Risk Of Respiratory Symptoms [11]. According International Regulations, As ANSI/ASHRAE Standard 55 [12] Is Recommended An Indoor Average Monthly Relative Humidity Below 80%. Then, From The German Standard DIN 4108-2 [13], The Records Of Surface Relative Humidity Above 80%, Along A Period Exceeding Six Hours, Allow The Formation Of Filamentous Fungi (Mould).

The Use Of Thermal Insulation On External Façades Has Demonstrated To Be Efficient To Reduce The Indoor Temperature Peaks In Cities Located In The Southern Brazil [14]. This Region Differs From The Rest Of The Country Due To The Humid Subtropical Temperate Climate, In Which There Is A Need To Define Strategies For The Thermal Comfort For Cooling And Heating. According To NBR 15220-3 [15], Brazil Is Divided Into 8 Bioclimatic Zones, With Bioclimatic Zones 1 And 2 Being The Coldest Ones.

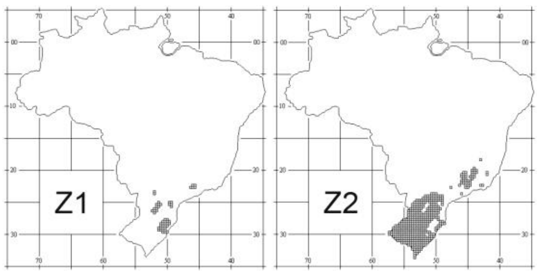

Figure 1 - Bioclimatic Zones In Brazil, Including The Zone 1 And Zone 2 [15].

The Brazilian Regulations Present Values Restrictions For Thermal Transmittance, But There Are Not Recommendations To Avoid Condensation In Buildings To Prevent The Formation Of Mould. However, Some Studies Have Shown The Possibility Of Occurrence Of Condensation On Internal Wall Façades [16], And Also About The Maximum Transmission Coefficient To Avoid The Formation Of Fungi On Interior Wall Surfaces [17], Besides The Possibility Of Fungi Formation In Thermal Bridges [18]. Due To These Points, The Aim Of This Paper Is To Analyze Through Computational Simulation The Influence Of Thermal Insulation Thickness (Placed On The External Building Wall) On The Relative Humidity Conditions For Mould Formation In A Single-Family Dwelling Sited In Bioclimatic Zones 1 And 2.

II. METHODS

The Study Consists Of An Analysis From Data Generated By Computer Simulation, Energyplus Software Version 8.8. The Process Involves 4 Steps: Modelling, Simulation, Data Processing And Result Analysis. The Building Is A Typical Single Family Dwelling In Brazil With Two Dormitories, With 57,75 M² Floor Area, According To Fig. 2. The Building Was Modelled Using Sketchup PRO Software With The Open Studio Plug-In.

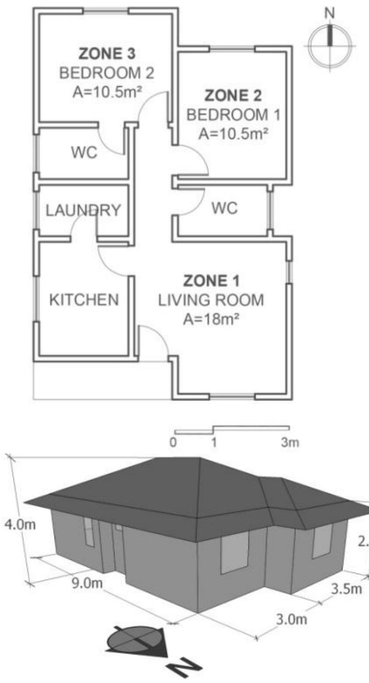

Figure 2 - Baseline Model Including The Floor Plan And Isometric View.

The Study Focused On The Dormitory 2, It Has A Good Solar Orientation (North), And A 10,5 M² Aperture Under A Window-To-Floor Ratio Of 14%, With Partial Protection By Eaves Of 800mm Depth. The Building Has Masonry Walls With Clay Blocks, Floor And Ceiling Of Concrete Slab, Roof With Wooden Structure, Insulation Foam And Ceramic Tiles. Table 1 Presents The Thermal Transmittance Data For The Baseline Model And The Total Transmittances For Each Of The Three Options Of Thermal Insulation Thickness (Rockwool - Thermal Conductivity = 0,045 W/Mk): 25, 50 And 100mm, Applied To The External Face Of The Building.

Table 1 - Transmittance Values For The Baseline Model (Without Insulation) And For The External Wall + Thermal Insulation Under Different Thicknesses.

Construction	U (W/M²-K) + Thermal Insulation				Reflectance
	Baseline Model	25 Mm	50 Mm	100 mm	
Wall	2,38	1,02	0,65	0,38	0,5
Floor	4,04				0,5
Ceiling	3,34				0,5
Roof	2,30				0,5
Window	Glass U-Value (W/M²-K)	5,89	SHGC		0,87

Internal Thermal Loads Densities And Schedules For The Baseline Model Were Defined According To The Rules Adopted For Simulation Procedure Described In The Brazilian Regulation For Energy Efficiency In Residential Buildings [19]. The Adopted Ventilation Standard Is The Selective One, Which Allows Windows Open When The Indoor Air Temperature Is Higher Than Outdoor Temperature (Ti≥To), And When The Outdoor Temperature To>20°C. As The Baseline Model Is A Single Floor Building, With Direct Contact With The Ground. For This Case The Influence Of Ground Temperature On The Building Thermal Performance Is Significant. Therefore, To Be Obtained The Monthly Mean Ground Temperature, Was Used The Slab Program, Available In The Energyplus Software.

The Simulations Were Carried Out For The Cities Of Curitiba/PR (Bioclimatic Zone 1) And Santa Maria/RS (Bioclimatic Zone 2). Table 2 Presents The Extremes Temperatures And The Mean Values For The Annual Dry Bulb Temperature Of Each City. Also At The Right Of Table 2 Are Shown The Calculated Values Of *Heating Degree-Hours (HDH)* For A Base Temperature Of 18°C, According (Eq.1), And The *Cooling Degree-Hours (CDH)* For A Base Temperature Of 26°C, See (Eq.2). It Can Be Observed That Curitiba (CTB) Requires More Heating Degree-Hours, And Less Cooling-Hours Than Santa Maria (SMA).

Table 2. - Summary Of Description Data Of The Cities

City	Annual Lowes	Annual Mean	Annual Highes	HDH18	CDH26

	t Temp (°C)	Temp (°C)	t Temp (°C)		
CTB	-0.1	17.3	31.7	19294	484
SMA	-0.2	18.9	38.3	18164	3548

$$HDH18 = \sum_{h=1}^{8760} (18 - Ti)\ if\ To < 18°C \qquad (1)$$

$$CDH26 = \sum_{h=1}^{8760} (Ti - 26)\ if\ To > 26°C \qquad (2)$$

Where *H* Is The Hour Of The Year, *Ti* (°C) Represents The Indoor Dry Bulb Temperature, And *To* (°C) The Outdoor Dry Bulb Temperature.

III. RESULTS

The Relative Humidity On Indoor Façades Was Obtained From The Interior Wall Façade Tempera-Ture And The Zone Mean Air Humidity Ratio [20]. The Intent Is To Verify The Amount Of Occurrences In Which This Humidity Remains Higher Than 80% For More Than 6 Hours. This Period Can Be Suitable For Fungi Formation According To DIN 4108-2:2013. It Was Also Quantified The Total Occurrences In Which The Surface Relative Humidity Exceeds 80% For More Than Periods Of 12 Hours And 24 Hours, In Order To Evidence The Greater Probability Of Occurrence Of Mould. Each Occurrence Corresponds To One Hour Of 8760 Simulated Hours, Throughout The Year. Fig. 3 Presents The Results For The Cities Of Curitiba/PR (Zone 1) And Santa Maria/RS (Zone 2).

From The Analysis Performed, The Number Of Occurrences The Surface Relative Humidity Exceeds 80% For More Than 6 Hours, For The Base-Line Model Are 4211 And 3417 For Curitiba/PR And Santa Maria/RS, Respectively. These Numbers Represent About 48% And 39% From The Total Simulated Hours (8760). Therefore, It Becomes Evident A High Possibility Of Mould Occurrence Already For The Baseline Model. Also, It Can Be Seen That The Quantity Of Occurrences Increases To 18% And 22% Higher For Curitiba/PR And Santa Maria/RS, Respectively, When Comparing Baseline Model With The Case With Greater Insulation (100mm).

Also, Is Shown In Fig. 3, For The Two Cities, The Large Number Of Occurrences That The Surface Relative Humidity Was Above 80% For More Than 12 Hours. These Numbers For The Baseline Model Are 3072 And 2501, In Curitiba/PR And Santa Maria/RS, Respectively, 35% And 28% Of The Total Number Of Hours Simulated (8760). When Evaluated For More Than 24 Hours, The Number Of Occurrences In 1993 And 1649 Recorded Corresponds To 22% And 18% Of The Total Number Of Simulated Hours (8760). These Findings Are Alarming And, Partly Reflect The Climatic Conditions Of The Two Cities Analyzed. This Is Possible To See When Evaluating The Outdoor Relative Humidity, The City Of Curitiba/PR, Presents 5354 Hours And Santa Maris/RS With 4574 Hours, Representing 61% And 52% From The Total Hours Of The Year. Fig. 4 Shows The Records Of Outdoor Dry Bulb Temperature (°C) And Outdoor Relative Humidity (%) Throughout The Year.

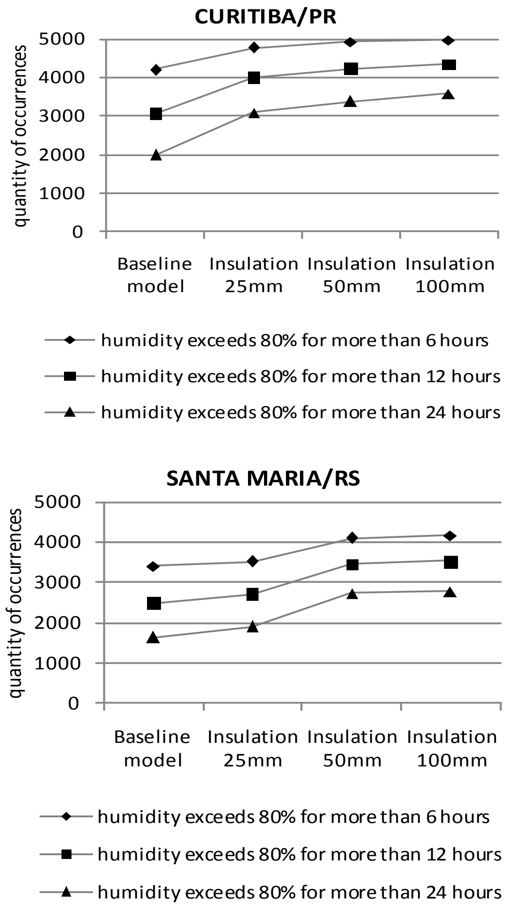

Figure 3 - Probability Of Occurrence Of Mould In Curitiba/PR And Santa Maria/RS.

Comparing Fig. 4 And 5, It Is Possible To Verify The Impact Of The Conditioning And Insulation Of The Envelope On The Temperature And The Surface Relative Humidity. These Images Allow Verify The Large Number Of Relative Humidity Registers Above 80%. It Can Be Inferred That When The Thermal Insulation Is Applied On The Outside Wall Façade This Will Prevent Moisture Dissipation, And Then Maintaining For Longer The Condition Of Relative Humidity Higher Than 80%, Favouring Conditions For Fungi Formation.

Tables 3 And 4 Present The Extremes And Average Values For The Annual Zone Operative Temperature, The Heating Degree-Hours (HDH) For

Base Temperature Of 18°C And The Cooling Degree-Hours (CDH) For Base Temperature Of 26°C For The Baseline Model And Case With Greater Insulation (100mm) In Curitiba/PR And Santa Maria/RS. It Is Verified That The Thermal Insulation Provides An Amplitude Reduction Between The Maximum And Minimum Temperatures, Comparing With The Data Presented In Table 2.

Table 3 – Indoor Thermal Condition For CTB

Case	Annual Lowest Temp (°C)	Annual Mean Temp (°C)	Annual Highest Temp (°C)	HDH18	CDH26
Base	12,67	18,19	24,44	8570	0
100mm	13,58	18,17	23,18	8045	0

Table 4 – Indoor Thermal Condition For SMA

City	Annual Lowest Temp (°C)	Annual Mean Temp (°C)	Annual Highest Temp (°C)	HDH18	CDH26
Base	11,79	19,70	28,99	7889	428
100 mm	13,11	19,73	27,56	7073	148

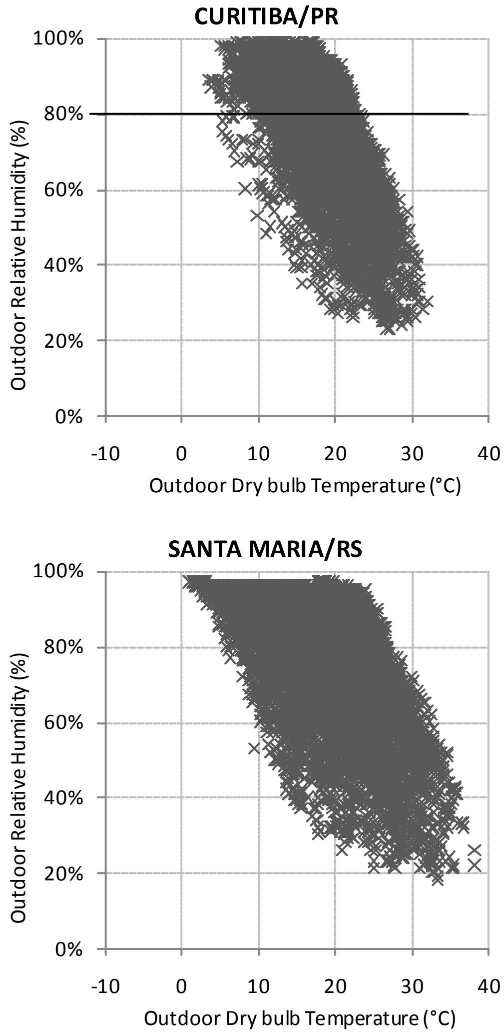

Figure 4 - Records Of Outdoor Dry Bulb Temperature (°C) And Outdoor Relative Humidity (%) In Curitiba/PR And Santa Maria/RS.

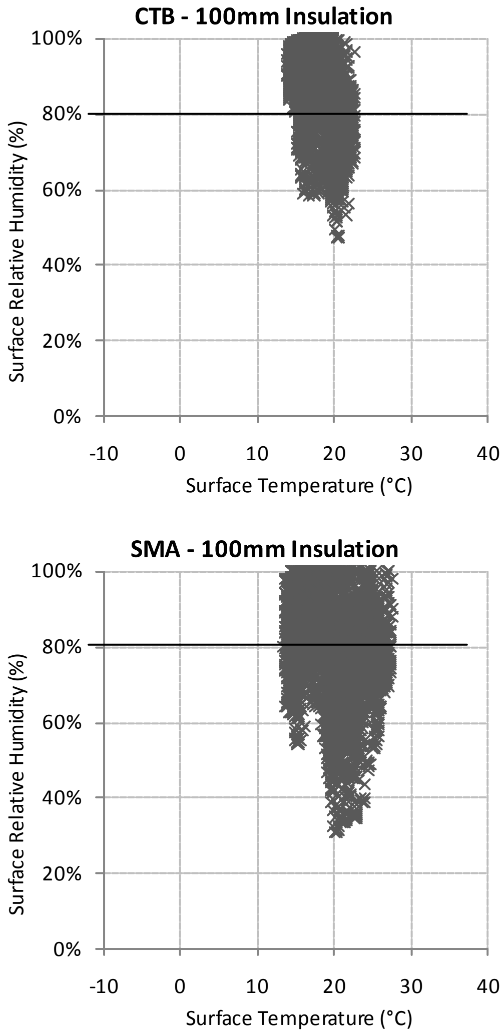

Figure 5 - Surface Temperature (°C) And Surface Relative Humidity (%) For The 100mm Insulation Case In Curitiba/PR And Santa Maria/RS

This Occurrence Of High Indoor Relative Humidity May Be Partly Associated To The Ventilation Aperture Control System Responsible To Provide Airflow Make-Up. The Brazilian Standard Describing The Simulation Procedure For Simulation For A Controlled Ventilated House [19], Defines The Admittance Of Air Flow Through An Opening Automated, When The Indoor Temperature Is Higher Than Outdoor Temperature, And When This Last Temperature Is Higher Than 20°C. This Definition Tries To Follow A Required Standard To Optimize The Indoor Thermal Conditions. However, As Can Be Seen In Fig. 6, Is Not Considered The Indoor Humidity Role Along Cool And Cold Periods Of The Year. Thus, Can Be Observed From Fig. 7 That Even In Warmer Period (October – April), Under A High Rate Of Make-Up Airflow, Occurs Relative Humidity Values Higher Than 80%. The Outdoor Relative Humidity Of Air Is Considerably High In The Southern Brazilian Region. This Fact Associated With The Reduction Of The Make-Up Airflow During Cool Or Cold Months, In The Attempt To Maintain Comfort Thermal Conditions, Can In-Crease A High Indoor Humidity Level.

Adopting A Hypothetical Condition Of 5 Air Changes Per Hour (ACH) In The Warmer Period (October To April) And Only 1 Air Change Per Hour In The Colder Months, Fig. 7 Shows A Reduction Of Almost 50% (6137 To 3049) From The Number Of Records Of Indoor Relative Humidity Above 80%. Evaluating The Thermal Condition, Comparing To Table 3, From The Amount Of Degree-Hours, It Was Found A Reduction Of The Heating Requirement Of 8045 Degree-Hours Of The Case With 100mm Of Insulation To 7254 Degree Hours Based On The Temperature Of 18°C And The Maintenance Of No Record Of Cooling Degree-Hour Based On The Temperature Of 26°C, For The Simulation Performed For The City Of Curitiba/PR. Fig. 8 And 9 Shows The Variation Of CO2 Concentration For The Two Ventilation Standards Adopted. Comparing The Figures, The Constant Air Exchanges Even Provided A CO2 Concentration At More Acceptable Levels.

Although This New Simulation May Have Provided A Reduction Of Relative Humidity Above 80%, A Large Number Of Records (3049) Still Exist, Accounting For 35% Of The Hours Throughout The Year, Reinforcing The Need To Search For Alternatives That Provide Healthy And Comfortable Environments In These Two Climatic Zones.

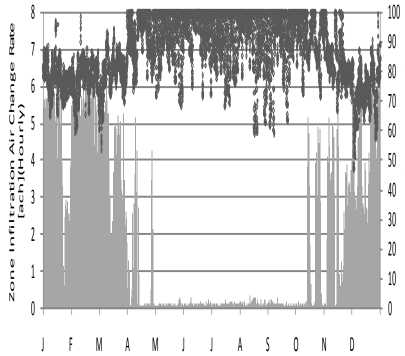

Figure 6 - Make-Up Airflow Rate And Indoor Relative Humidity Along The Year: 100mm Insulation, Curitiba/PR: Controlled Ventilated Adopted By Brazilian Standard.

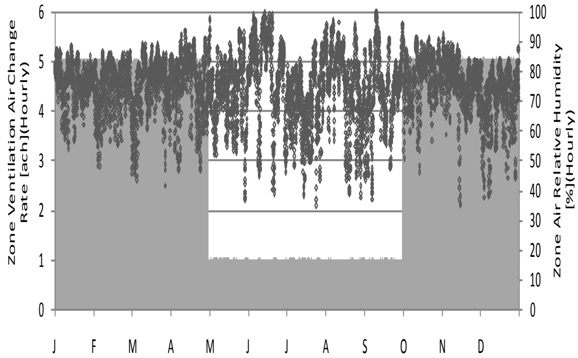

Figure 7 - Make-Up Airflow Rate And Indoor Relative Humidity Along The Year: 100mm Insulation, Curitiba/PR: Ventilation Condition Of 5 ACH In The Warmer Months And 1 ACH In The Colder Months.

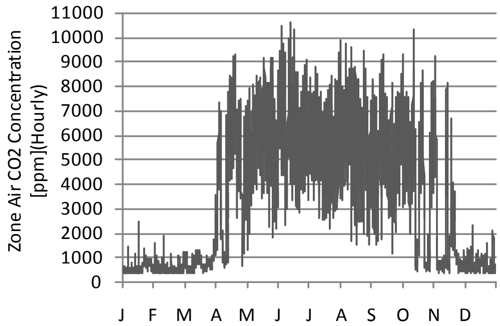

Figure 8 - Indoor CO2 Concentration Along The Year For The 100mm Insulation Case In Curitiba/PR: Controlled Ventilated Adopted By Brazilian Standard

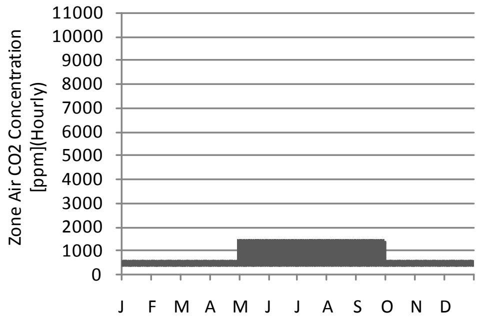

Figure 9 - Indoor CO2 Concentration Along The Year For The 100mm Insulation Case In Curitiba/PR: Ventilation Condition Of 5 ACH In The Warmer Months And 1 ACH In The Colder Months.

IV. CONCLUSION

This Paper Was Focusing The Influence Of Thermal Insulation Thickness Versus Moisture Content On Indoor Wall Faces For A House Typology, Sited In Two Brazilian Cities With Climatic Conditions Of The South Region. It Was Verified By Simulations, That The Building For The Baseline Model (Without Insulation) And For The Other Cases With The Application Of Several Thicknesses Of Thermal Insulation, Present Good Results Related With Thermal Conditioning. The Baseline Model Presents 40% Of The Yearly Hours With Interior Wall Face With Relative Humidity Higher Than 80% For More Than 6 Hours, Allowing The Formation Of Fungi And Problems About Indoor Air Quality And Possible Impact On The Occupant Health. It Was Also Verified That The Thermal Insulation On The Outside Wall Can Increases Around 20% (Higher Thickness Case) The Amount Of Hours With Relative Humidity More Than 80% On Indoor Surfaces. In Event, This High Level Of Indoor Relative Humidity Can Be Partially Associated With The Automated Opening Control Rule, Defined By The Brazilian Standard For Simulation Of Controlled Ventilation In Residential Buildings. In Addition The Need To Revise The Regulations, The Study Indicates To Be Required More Research Related With The Subjects Presented, Especially Regarding The Mould Inception On Indoor Building Walls, And Active Ventilation Ways To Provide An Indoor Air Quality, Especially During Cold Months, In Mild Tropical Humid Climates.

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