PRACTICAL EXPERIENCE IN DESIGN, APPLICATION AND FIELD PERFORMANCE OF ROOFING IN DEVELOPING COUNTRIES: THE SPECIAL CASE OF ARGENTINA

MARIA P. LOPEZ DIAZ and ALEJANDRA OROZ
Roofing Technology Research Center
Buenos Aires, Argentina

Argentina is considered a developing country, but some special considerations must be posed about its construction industry. At the beginning of this century the building materials used, the projects, the technology involved and the performance obtained placed this industry in a remarkable position.

Today, there is a heterogeneous market that produces the coexistence of traditional techniques and materials with a broad variety of new materials and technologies. This, along with the territorial extension, the wide variety of climates and the need for budget cuts, has caused the main pathologies found in the construction industry.

The Roofing Technology Research Center (CITE), which began its activities in 1989, is devoted to the study of roofing pathologies, their causes and possible solutions and the implementation of test techniques for new materials and systems.

This paper intends to analyze the climatic and atmospheric conditioning that influence the design the performance of roofs in Argentina.

KEYWORDS

Argentina, climate conditions, Roofing Technology Research Center (CITE), snow loads, wind speeds.

BASIC CLIMATIC CONDITIONS

There are several conditions for the designer of roofing constructions.

The first condition addresses the limitations and specific needs given by climatic and geographic factors. This country is known to have a "moderate" climate, but actually the different existing climates run from hot to cold. Additionally, the concept of "micro-climate" is paramount for the correct conception of a particular roof.

The starting point is the climatic charts of Argentina (see Figures 1[1], 2[2] and 3[3]).

To take into account the local climate, three different cities of Argentina are considered as examples (Figure 1): La Rioja, Buenos Aires and Ushuaia.

INFLUENCE OF CLIMATIC AND ATMOSPHERIC FACTORS

The influence of the main climatic and atmospheric factors is shown in Table 1, where:

- E.D. Exposure degree[2]
- P1 Covered: surfaces covered by a great number of obstructions, downtowns of big cities with general construction of more than 25m height.
- P2 Normal: undulated or forested areas, urban areas, urban areas with a large number of obstructions of closed spaces which have the houses height with an average not higher than 10m. For example industrial areas, suburbs of large cities.
- P3 Exposed: plain zones without or with some obstructions with an average of probable obstructions around the construction under 1.5m. For example: cost, zones up to 6 km, plains without trees, desert, etc. Plain zones not very undulated with obstructions scattered like fences, trees or very isolated constructions with heights between 1.5m and 10m.

Medium Annual Precipitation:

- I1 Scarce, if $I \leq$ 500mm/year.
- I2 Normal, if $500 < I \leq$ 1000mm/year.
- I3 Heavy, if $I >$ 1000mm/year.

Until a general micro-climate classification is achieved, we must consider medium annual precipitation. In addition, we must know at the job-site the intensity of the precipitation, because there may be zones that present similar mean values but with different distribution. This difference acts on the degree of severity of the exposure to which the roof will be subjected.

Degree of Exposure Severity:

- E1 Small
- E2 Medium
- E3 Large

Interior Relative Humidity[4]

Considering the city of La Rioja in May, when the mean external temperature is 15.1°C and the mean external relative humidity is 65 percent it can be observed from Figure 4 that the curves represent the mean internal temperature and the mean internal relative humidity for different values of internal pressure.

These curves are examples of different internal climates and show different condensation risks:

Pa = 1 pascal = 1 N/m2 = 0.102 Kg/m2

- I 1100 Pa $\leq$ Pi $<$ 1165 Pa No condensation risk.
- II 1165 Pa $\leq$ Pi $<$ 1370 Pa Small condensation risk.

- III 1370 Pa $\leq$ Pi $<$ Pa Medium condensation risk.
- IV 1500 Pa $\leq$ Pi Large condensation risk.

Taking into account the four selected interior pressure values (pi), the ventilation requirements will be different (see Figure 4):

- II Control of the HR (%), by means of normal ventilation.
- III Requirement of good ventilation: one full renewal each hour (1 vol/hour).
- IV Climatized building, HR % = 60 percent and considering hot and dry external air.

Snow

Within the zone of Figure 3, it is necessary to differentiate specific characteristics of snow precipitations.

The basic snow load (qo) is the snow weight that can be accumulated on the terrain.

- Zone I: No snow precipitations.
- Zone II: It is considered that in this zone normal, frequent or extraordinary snowfalls may occur.
  - Locations with infrequent or extraordinary snow precipitations. qo: 0.3 KN/m2
  - Locations with occasional snow precipitations during the year. qo: 0.9 KN/m2
  - Locations with frequent snow precipitations during the winter. qo: 2.0 KN/m2
  - Locations with frequent snow precipitations all year. qo: 3.2 KN/m2

STUDY OF PATHOLOGIES

One statistical study,[5] considering 198 neighborhoods representing 31,414 houses distributed throughout Argentina, fully reflects the main pathologies observed. For the construction of the 198 neighborhoods, 59 industrialized systems were used.

This study divided the country in five regions (Figure 5):

- Center—75 neighborhoods.
- Patagonia (South)—40 neighborhoods.
- Cuyo (Center Andean)—5 neighborhoods.
- Northeast—45 neighborhoods.
- Northwest—28 neighborhoods.

The main pathologies found are (Table 2):

- In heavy systems—Little watertightness in joints and existence of thermal bridges.
- In light systems—Problems in watertightness of roof, existence of thermal bridges and corrosion of steel elements.

The age of the construction varies within three to five years and, considering the projected durability of buildings in Argentina is 50 years, it must be concluded that results of industrial system construction are not satisfactory.

Within the causes of these pathologies, the following can be observed:

- Use of untested technology.
- Changes in building materials without considering their previous performance.
- Transportation of building materials for long distances without taking the necessary precautions.
- Adaption of construction systems without a prior thorough study.

In another statistical study,[6] six neighborhoods surrounding Buenos Aires were analyzed, totaling 13,272 houses. Considering the construction system and the materials involved in each case, it can be divided as follows:

- 5,300 Structure: Concrete slab.
  Hydraulic isolation: Traditional asphalt multilayer.
- 3,984 Structure: Concrete slab.
  Hydraulic isolation: Floating membrane.
- 1,500 Structure: Concrete slab.
  Hydraulic isolation: Traditional asphalt multilayer.
  Thermal insulation: Unconfined clay expanded.
- 1,188 Structure: Concrete slab.
  Hydraulic isolation: Traditional asphalt multilayer.
  Thermal insulation: Ceramic masonry blocks.
- 1,300 Structure: Concrete slab.
  Hydraulic isolation: Mixed system (membrane and asphalt).

The main causes of failure observed in the roofing systems of these neighborhoods are:

- Inadequate design of the hydraulic cover, which cannot follow the deformations of the base. This fact is evident through the presence of cracks between the slab and the hydraulic isolation.
- No compliance of standards and codes.
- Lack of quality control during the project.
- Inadequate design.
- In some cases the project is not controlled during the construction of the roof.
- Inefficient repairs.

CONCLUSION AND RECOMMENDATIONS

- The concept of adequate technique is often forgotten. This indicates that for every project the most suitable solution must be found, with regard to environment, climatology, culture, available materials, etc.
- The lack of adequate and comprehensive climatic data is remarkable. Emphasis must be put in the collection of suitable and reliable data.
- When considering any new project, the cost of the roofing system must include not only the construction cost but also the maintenance cost and durability.
- The misunderstanding and incorrect use of technical specifications and codes is a common practice.
- The author considers that the use of the presented tables facilitates the achievement of a good design and the desired performance.

From the analysis of the values described in Table 2 and in spite of the fact that to obtain an extensive conclusion is necessary to conduct a statistical study using these first results as a basis, the existing relations between the climatic characteristics of each one and the pathologies detected can begin to be described.

Arranging the pathologies found in each zone in accordance with their importance in a decreasing way follows (see Figure 1):

- Center—Warm (II) and warmly moderate (III).

Superficial condensation in walls and roofs added to an inefficient thermic isolation. Both pathologies have their origin in an inadequate thermic isolation that acquires importance owing to the maximum temperatures reached in summer, season during which greater thermic amplitudes are achieved (16°C).

The crossed ventilation of the house and the use of a big thermic isolation is fundamental in this zone. Failures in covering causes water infiltration.

- Patagonia—Coldly moderate (IV), cold (V) and very cold (VI).

There is superficial condensation in walls and roofs. The high level of relative humidity and the crude winters characterize this zone. Avoiding thermal bridges is important.

Failures in covering is due to strong winds (flyed) and water infiltration is due to snowfall action. There is also inefficient thermal isolations.

- Cuyo—Very cold (VI), coldly moderate (IV) and warmly moderate (III). There is a large zone with the typical mountain climate. It is a region of large thermal amplitudes. The number of buildings is too scarce for any conclusions to be drawn. Further study of the zone pathologies is necessary. However, the main pathologies indicated failures in covering.

- NEA—Very warm (I) and warm (II).

Failures in covering cause water infiltration. There is superficial condensation and inefficient thermal isolations (lack of blackout elements and eaves).

This climate is characterized by the high level of relative humidity and high temperatures. Crossed ventilation and a large thermal isolation is needed.

- NWA—The climate of this zone varies from very cold (mountain) at the west to hot at the east; owing to this, the pathologies observed vary.

There is superficial condensation and inefficient thermal isolations. Failures in covering cause water infiltration.

West zone owing to the large thermal amplitudes, pathologies due to inefficient thermal isolation acquire importance.

REFERENCES

[1] "Norma IRAM 11603," (BASIC CLIMATIC CONDITIONS).

[2] "Reglamento CIRSOC 102 (Centro de Investigacion de los Reglamentos Nacionales de Seguridad para las Obras Civiles)," (E.D. Exposure degree).

[3] "Reglamento CIRSOC 104," (Snow loads).

[4] "Toitures dans les Pays en Developpement. Premiere Approche D'un Classement de Performances Etancheite a l'eau et Durabilite" fiche n 85 06 001 1987 CSTB, (Interior Relative Humidity).

[5] "Evaluacion de la Construccion Industrializada en los Programas FONAVI" Jng. Horacio Mac Donnell, Directorr Nacional de Tecnologia de la SVDA N 25 (Revista de la Camara Argentina de la Vivienda Economica de la Republica Argentina), (STUDY OF PATHOLOGIES).

[6] "Durabilidad y patologia de los materiales en conjuntos de vivienda economica" UBA Facultad de Arquitectura y Urbanismo, OEA Organizacion de los Estados Americanos e JNTI Instituto Nacional de Tecnologia Industrial, (Study of six neighborhoods surrounding Buenos Aires).

[7] Hoja de informacion tecnica referida a techos "Importancia del comportamiento termico de techos" T.A. Nota Dic 89, CITE, (Table 1 Influence of climatic factors).

[8] Hoja de informacion tecnica sobre patologia de techos "Condensacion superficial" T.A. Pat j Dic 89, CITE, (Table 1 Influence of climatic factors).

<table>
<tr><th>Unit</th><th colspan="2">Climatic Data</th><th>Design: Main factors to be considered</th><th>Examples</th></tr>
<tr>
<td>•E.W.N.S.

•m/s

P1 Covered
P2 Normal
P3 Exposed</td>
<td>W
I
N
D</td>
<td>• Main orientation

•Max speed

•Exposure degree</td>
<td>□Watertightness:
•Orientation of sloping roofs

•Kind of fastening for sloping or flat roof

•Need for ballasting

□Durability:
•Materials erosion
•Pull-off
•Kind of fastening</td>
<td>A□V : 25 m/s S.
Risk of:
pull-off and erosion is minimum.
B□V : 27.5 m/s E.
Risk of pull-off and erosion is medium.
C□V : 40 m/s SW.
Risk of pull-off and erosion is maximum.</td>
</tr>
<tr>
<td>•mm/year

•I1 Scarce
I2 Normal
I3 Heavy

a) Not frequent
b) Frequent
c) Very frequent</td>
<td>P
R
E
C
I
P
I
T
A
T
I
O
N
S</td>
<td>•Medium annual precipitation (I)
•Intensity

•Frequency</td>
<td>□Watertightness:
•From data we choose materials considering their permeability to water
For example:
metals
membranes ► permeability
ceramic

□Durability:
precipitations scarce ◄corrosion risk
normal ►corrosion risk
heavy ◄corrosion risk than medium because they clear the surface.</td>
<td>A□Medium annual precipitations (I1)
Not frequent

B□Medium annual precipitations (I3)
Frequent

C□Medium annual precipitations (12)
Frequent</td>
</tr>
<tr>
<td>Probability (%)

•E1 Small
E2 Medium
E3 Large</td>
<td>WIND RAINFALL
CONCOMITANCE</td>
<td>•Maximum wind speed in accordance with precipitations. These data must be obtained by the designer at the job-site.

•Degree of severity to the exposure</td>
<td>□Watertightness:
•The roof slope is designed in accordance to the degree of severity to the exposure that emerges from the concomitance wind-rainfall. It is a first attempt and until further suitable data collection is done, the following table is proposed:
<table>
<tr><th>V Wind
precipitations:</th><th>V1</th><th>V2</th><th>V3</th></tr>
<tr><td>I1</td><td>E1</td><td>E2</td><td>E3</td></tr>
<tr><td>I2</td><td>E1</td><td>E2</td><td>E3</td></tr>
<tr><td>I3</td><td>E2</td><td>E3</td><td>E3</td></tr>
</table>
E1: degree small E2: degree medium
E3: degree large</td>
<td>A□Maximum wind speed : V1
Medium annual precipitations: I1
Degree of severity: E1
B□Maximum wind speed: V2
Medium annual precipitations: I3
Degree of severity: E3
C□Maximum wind speed: V3
Medium annual precipitations: I2
Degree of severity : E3</td>
</tr>
</table>

Table 1 *Influence of climatic factors.*

Unit	Climatic Data		Design: Main factors to be considered	Examples
•T°C mm/year •T°C mm/year •DT°C	CONCOMITANCE RAINFALL TEMPERATURE	•Precipitations with low temperatures. •Precipitations with high temperatures. •Big variations of temperatures	□Durability:[7] •Water + cold: produces physical degradation of materials. •Water + heat: produces biological corrosion of materials and speeds chemical reactions. •Big variations of temperature, especially if produced in short periods of times, cause important dilatation and contraction of the materials.	A□High temperatures and big variations of temperature. B□Low probability C□Low temperatures.
•% •%	RELATIVE HUMIDITY	•External medium relative humidity HRe. a) High ► 65% b) Low ◄̲ 65% Internal medium relative humidity HRi	□Watertightness: •High external relative humidity unables the drying and allows the saturation of absorbent materials and the corrosion of metals. □Durability: •High internal relative humidity produces high condensation risk in the interior and production of moss and mushroom. •We must consider:[8] a) Destination b) Type of materials c) Occupation factor d) Relation between external and internal ambients e) Avoid heating systems that produce steam f) Design of adequate ventilation g) Avoidance of thermal bridges •For moderate climate HRe 65% and external temperature 15° different internal climates were studied, including the existing condensation risk[9] In Figure 6 an example is shown.	A□The external relative humidity is low ◄ 65% B□The external relative humidity is high ► 65% C□The external relative humidity is high ► 65%

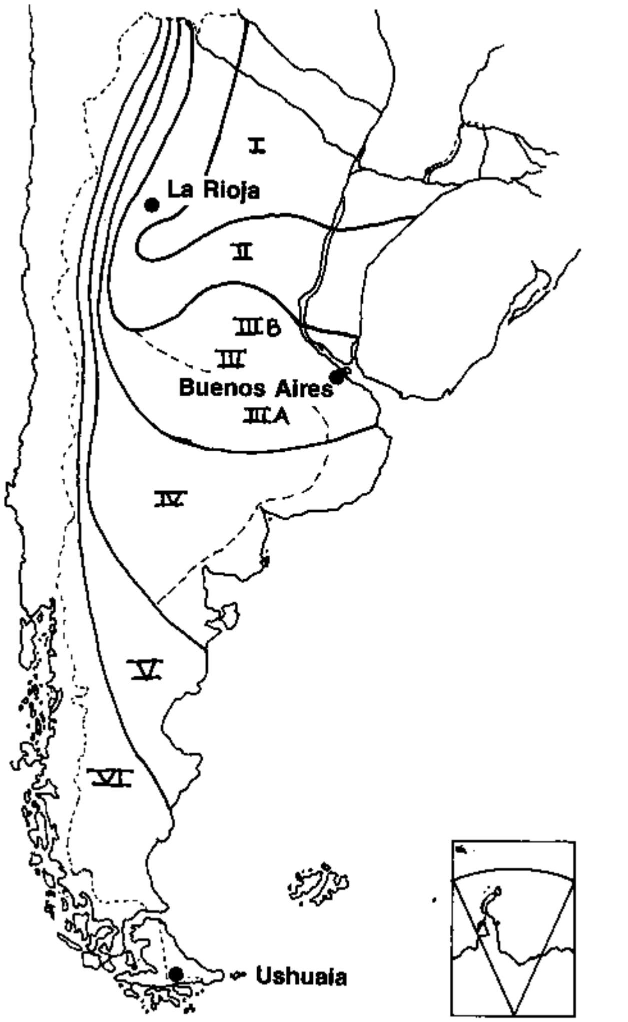
Table 1 *Influence of climatic factors.*

Unit	Climatic Data		Design: Main factors to be considered	Examples
•mm	SNOWFALL	•Precipitations •Frequency	□Watertightness: •Existing constant water pressure •Covering porosity analysis •Roof slope to facilitate snow evacuation •Covering of the roof elements that must be greater than usual •Thermal discontinuity Tint ► Text. In this condition spot accumulation are produced (snow + deicing water).	A□Zone II a) Not frequent or extraordinary snowfall B□Zone I Not snowfall C□Zone II b) Normal snowfall sometimes during the year
•MW/m •year	SOLAR RADIATION	•Intensity •Duration	□Durability: •Thermal effect of solar radiation •Degradation of the roofing materials by ultraviolet rays	
•% g / m	POLLUTION AND DUST	Ambient: •Rural (dust) •Marine (Cl-) •Industrial urban (S02,C02,etc) •Urban not industrial	□Durability: •Election of the material covering or the protection necessary by regards of the different ambients	A□Urban Industrial urban Dust possibility B□Urban Industrial urban C□Marine Urban not industrial

Table 1 Influence of climatic factors.

Zone (See Figure 5)	No. of Neighborhoods	Detected Pathologies % Referenced to Each Zone		
Hole Country	193	Failures in Covering	Superficial Condensation in Walls and Roofs	Unefficient Thermal Isolations
Center	75	19%	32%	13%
Patagonia (South)	40	15%	18%	2%
Cuyo (Center Andean)	5	80%	—	—
Northeast	45	33%	15%	13%
Northwest	28	32%	46%	29%

Table 2 Main pathologies found.



I	Very Warm	- summer average temperature winter average temperature	► 26°C ► 12°C
II	Warm	- summer average temperature 8°C ◄ winter average temperature	► 24°C ◄ 12°C
III	Warmly moderate	- summer average temperature winter average temperature	► 20°C ► 0°C
IV	Coldly moderate	- summer average temperature 4°C ◄ winter average temperature	◄ 30°C ◄ 8°C
V	Cold	- summer average temperature winter average temperature	◄ 16°C ◄ 4°C
VI	Very cold	- summer average temperature winter average temperature	◄ 12°C ◄ 4°C

Figure 1 *Climatic classification.*

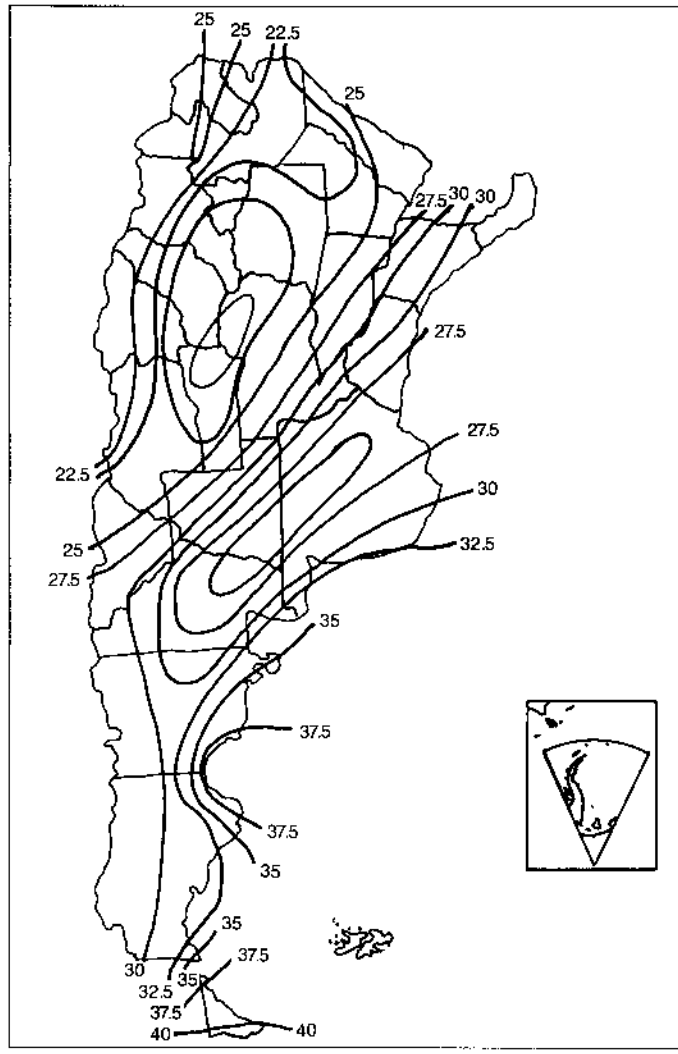


Figure 2 *Wind Speeds (Meters/Second).*

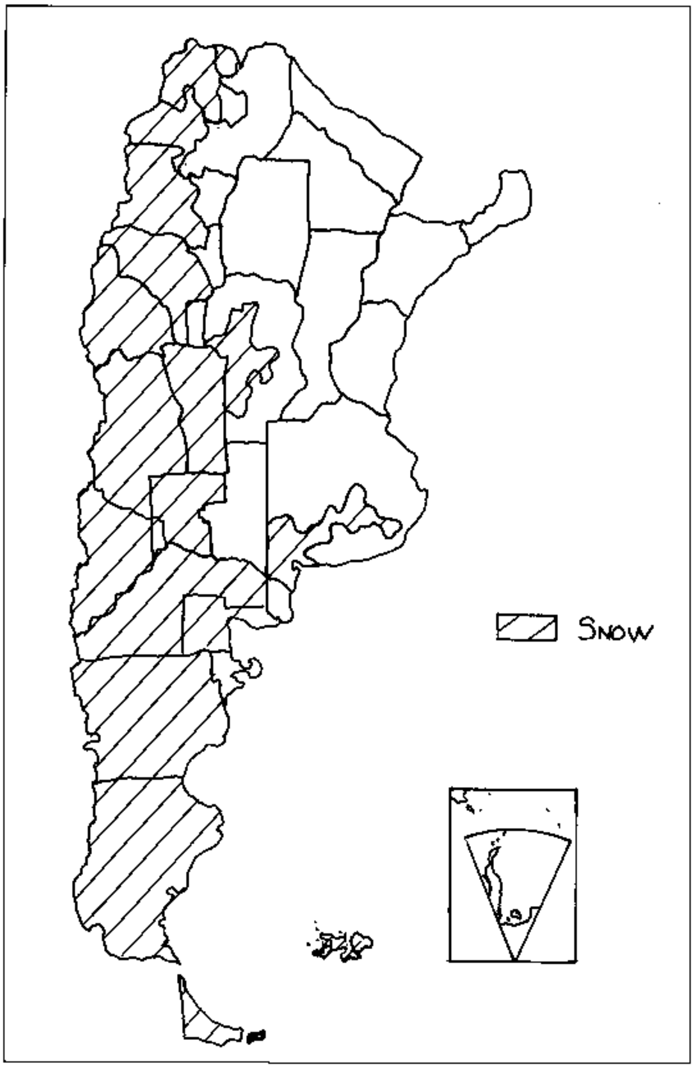


Figure 3 Snow Loads.

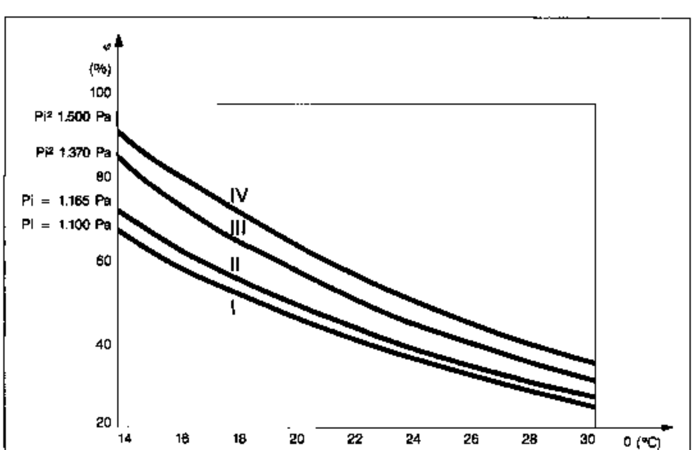


Figure 4 Interior relative humidity (θ) vs. interior temperature (θ).

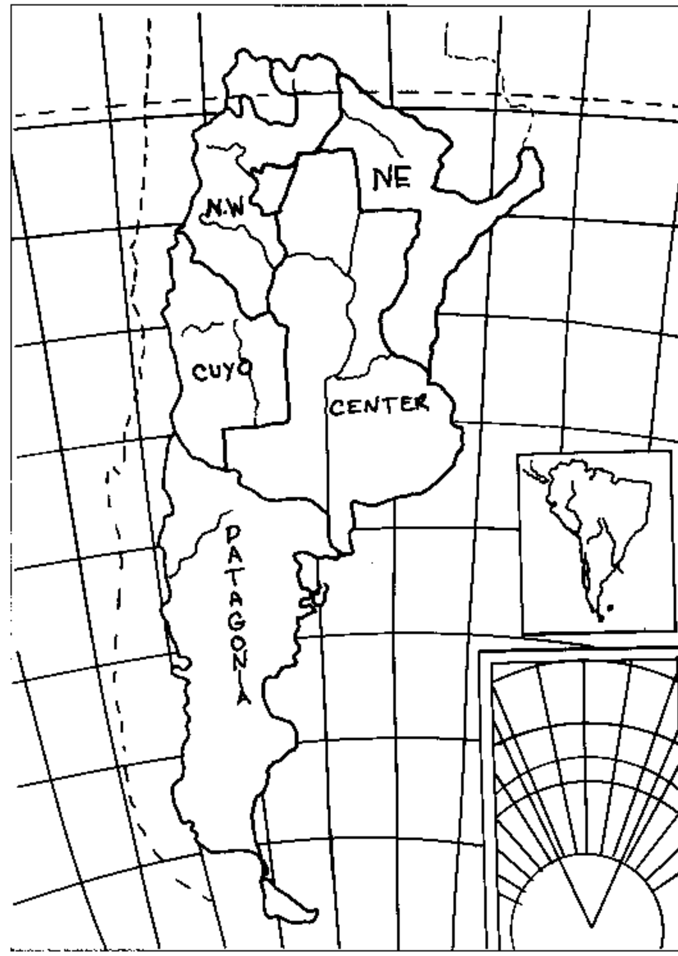


Figure 5 Regions of pathological study.