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Ignacio Requena-Ruiz

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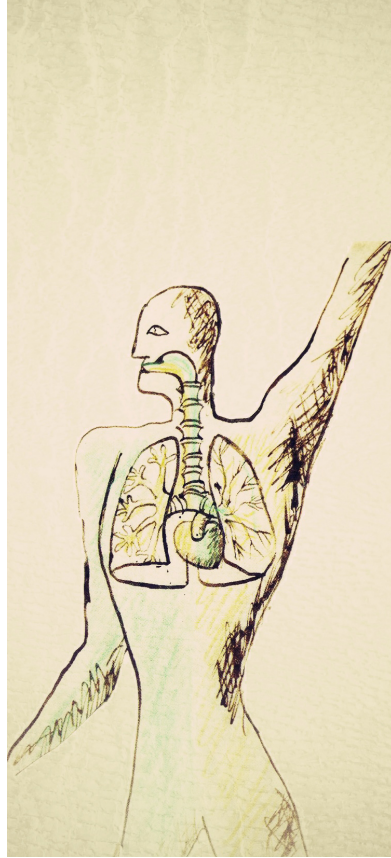
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Le Corbusier and André Missenard: From artificial climates to bioclimatic architecture (1937-1965)

Ignacio Requena Ruiz

Enseignant - Chercheur de l'École Nationale
Supérieure d'Architecture de Nantes (France)

Laboratoire CERMA, ENSA Nantes, 6 quai François
Mitterrand, BP16202, 44262 Nantes (France)

+33 (0)6 95 75 77 39 // ignacio.requena@cerma.archi.fr

ABSTRACT

The entire rethinking of society that Le Corbusier promoted through his particular notion of modern architecture involved the construction of the perfect atmosphere to house it. In this regard, the ocularcentrist approach was complemented by an increasing attention to the non-visible dimensions of architecture. Thus, thermal comfort became an influential topic, as evidenced in proposals like the *Air exact* or the *Brise-soleil*. The architect's experiments on thermal control, however, were a quite controversial matter throughout his work because of the great contradiction between his theories based on the Sun, physiology and climate and the real perceptions and troubles of the inhabitants.

Whilst his machinist conception of indoor climates during the 1920s has been already analysed, his evolution to an architecture that interacted with inhabitants and climates from the late-1930s, but especially in the 1950s, has only been cursorily studied.

In this regard, we state that the figure of the French engineer André Missenard was a touchstone in understanding the master's architecture as the construction of thermal ambiances. As a *thermicien* and physics lover, his influence on Le Corbusier not only involved technical fields (radiators design, radiant floor heating or *aérateurs*), but the whole notion of thermal comfort that he conceived for the modern society. As a result, the engineer's proposal of the Science of Artificial Climates brought together the contributions of physiology, technique and climatology to create a unique corpus of knowledge. His collaboration with Le Corbusier during the 1950s transformed the architect's works, in a laboratory of thermal comfort, for both of them.

This research studies the personal and professional relationship between Le Corbusier and Missenard between 1937 and 1965, a period when the architect's works were influenced by the engineer's approach to thermal comfort and environmental regulation systems. The research discusses how their collaborative works led to a different discernment in the relation between architecture, inhabitant and climate.

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1 INTRODUCTION

1.1 OVERVIEW AND JUSTIFICATION

Modern Architecture has been studied extensively as a phenomenon at the crossroads of the avant-gardism in art with the technical revolution of the early twentieth century. However, looking at the broader context of modernity, many researchers (Bauman 1991; Till 2009) indicate that matters previously considered at the origin of Modern Architecture, in fact were dependent on a much more powerful pattern of circumstances. That is to say that architectural modernism was rather a consequence of a whole context than a creation of modern architects. Or as Till argues, “Le Corbusier is seen in the wider picture not as the inventor of modernism (as architectural style and movement), but as an inevitable consequence of modernity (as a condition of society). He is a symptom, not a cause” (Till 2009, 33).

In recent years, architectural history has become increasingly interested in the challenge of understanding Modernism looking at neighbouring disciplines as a source of inspiration and encouragement, aiming to tamper the autonomy of architecture (Schorske 1998). A central issue in this regard is decoding the influence of hygienism in relation with scientific discoveries and industrial developments during the late-nineteenth and the early-twentieth centuries. As some authors have revealed (Canguilhem and Savage 2001; Feuerhahn 2009; Corbin 2014a) the hygienic matters were the evidence of a greater awareness of the milieu and its possible influences on human physiological and psychological reactions. Several researchers have paid attention to the influence of environmental scientific theories and engineering innovations in either the cultural or social arena. The most relevant for this research are: Beatriz Colomina *Privacy and Publicity: Modern Architecture as Mass Media* (1994) and *The Medical Body in Modern Architecture* (1997); Christina Cogdell *Eugenic design: streamlining America in the 1930s* (2004); Fabiola López-Duran *Eugenics in the Garden: Architecture, Medicine and Landscape from France to Latin America in the Early Twentieth Century* (2009); Marsha Ackerman *Cool comfort: America's romance with air-conditioning* (2002); and Mirko Zardini *Imperfect Health. The medicalization of architecture* (2012).

Following the theory of acquired characteristics of Lamarck, researchers accorded more importance to natural and social environments. Cooper (1998) and Ackermann (2002) have well documented that during the first decades of the twentieth century emerged an agreement among physiologists, engineers and industrialists to shape popular ideas on science in order to normalize standards of climatic desirability and indoor comfort. Such standards could only be provided by creating “manufactured weathers” or “artificial climates” inside the buildings. Thus, the architectural affection of air-conditioning was evidenced in new architectural typologies, like cinemas, department stores or offices (Arsenault 1984; Hobday 2010; Hawkes 2008).

However, this view was challenged by many other professionals that adopted the same comfort and climate notions around the world to promote both mechanical and passive techniques (Missenard 1937; Olgyay 1951; Wogenscky 1972). Despite the importance of this parallel approach, it is still not clear how other indoor-conditioning

techniques were implemented in Modern Architecture and how they linked their creations with the wider conscience of human environments.

In this context, only few researches have analysed how modern architects collaborated with distinguished professionals of different fields such as medicine, biology, acoustics, physiology, art, science and so forth. Their influence was no longer limited to construction consultancy, as they progressively became theorists of the built environment taking a primary role in architectural design. The question remains as to how their theories were applied in architectural design following the promise of buildings with prophylactic, curative and regenerative powers.

As a consciously modern man, Le Corbusier paid special attention throughout his career to his collaboration with physicians, engineers and specialists whose research on the human environments could be linked with his broader aims. These topics, however, were always controversial in his works due to the great contradiction between his solar and anthropocentric theory and the inhabitants' actual perception. Several cases exemplified this assertion from the thermal discomfort caused by the *Air exact* system in the late-1920s, to the overheating troubles at the *Unité d'habitation* of Marseille. In this sense, Le Corbusier's most complex proposals on architectural atmospheres appeared in the 1950s under the hand of his collaboration with André Missenard (1901-1989), when the construction of the notion of comfort was considered not to be an isolated topic that affects thermal services, but a global intricate issue for its whole urban and architectural conception. Despite of the importance of the atmospheric dimension of Le Corbusier's architecture, it remains unclear.

Many researchers have turned recently to the study of weatherising systems and strategies in the works of Le Corbusier. Vanessa Fernandez and Emmanuelle Gallo (2010) as well as Rosa Urbano (2012; 2013) worked on the *Mur neutralisant* and the *Respiration exacte* in the 1920s. Sung-Taeg Nam worked on the radiators role in Le Corbusier's works in the 1920s and early-1930s (Nam 2012). Daniel Siret dealt with the design and technical issues of the FLC's files *Etudes d'ensoleillement 1940* (Siret 2005a), *Ensoleillement 1951* (Siret 2005b) and *Grille Climatique 1951* (Siret 2005c). In a more general way, Siret has also approach the architect's approach to sunlight and the *brise-soleil* (Siret 2004; Siret 2005d; Siret 2012). However, less attention has been paid to the influence of Missenard and his collaborators in Le Corbusier and the *Atelier 35S*.

Recently, there have been some papers and theses describing the emergence of thermal comfort and its influence on the history of techniques, where Missenard occupied a main place. Main references are the works of Emmanuelle Gallo in the history of heating systems in France (Gallo 2006) and Giulia Marino in the history of thermal comfort systems (Marino 2014). In addition, Gallo's current work on Missenard (Gallo 2014), helps to place the person and his background. None of these researches, however, have dealt with a comprehensive approach to Le Corbusier and Missenard contributions.

This research focuses on the role of the French engineer and his works in the physiological definition of thermal comfort in Le Corbusier's works. Through his research and experiments in the Science of Artificial Climates, he suggested the construction of manufactured atmospheres that could interact with the human body's thermoregulatory system. Although Missenard's contribution to the modernity discourse in this topic was widely published at that time, few researchers have dealt

with his influence in the materialization of new architecture as an entire environment. Apart from his books and articles, there is a significant lack of information about the relation of his theories and researches to the architectural thought Le Corbusier or his colleagues.

In this report, we provide a novel approach to the collaborative work of Le Corbusier and Missenard with the aim of clarifying how their works dealt with thermal comfort and weatherising services by proposing a different relation to inhabitant's perception, indoor atmosphere and architecture. In this study, we propose a comprehensive analysis of the evolution of the notion of thermal comfort and its architectural affection in Le Corbusier's theories, methods and works. To do so, this research introduces an approach at the crossroads of the history of techniques, clarifying the development of the environmental control for the built environment, the sensory history, re-contextualizing the environmental specificities of Modern Architecture and the history of architecture.

The present report is the result of the research conducted in the framework of the *Grant for Young Researchers 2013* of the *Fondation Le Corbusier* from September 2013 to September 2014. The research work has been developed at the archives of the FLC, the funds of the *Bibliothèque Nationale de France* and the library of the *Cité de l'Architecture* and the CERMA laboratory (UMR CNRS 1563) of the *Ecole National Supérieure d'Architecture de Nantes*.

1.2 SCOPE, LIMITATIONS AND AIMS

In this study, we focus on understanding how Missenard influenced both Le Corbusier's thought and professional practice triggering an evolution within it, which carried him from the imagery of the isothermal building to the sphere of the artificial climates. Missenard's researches and patents on thermal comfort reflect an innovative manner of dealing with theory, systems and environments that was directly stamped on the *Atelier 355's* methods, drawings and works.

In order to cover all the collaboration between both architect and engineer, this research is limited to the period from the late-1930s, when Le Corbusier began to be in contact with the engineer's theories, until the end of the architect's works in 1965. Furthermore, the actual experience of some of the works has also been referenced by bibliographic analysis and personal interviews. The archival research has also been physically limited to the historical documents preserved at the archives of the *Fondation Le Corbusier*, the *Bibliothèque Nationale de France* (BNF) and the *Cité de l'Architecture et du Patrimoine*.

The aims of the present research are fourfold. Firstly, to reveal how Missenard's influence on Le Corbusier's led to a different discernment in the relation between architecture, inhabitant and climate. Secondly, to contribute to clarifying the controversy about Le Corbusier's approach to thermal comfort and environmental services. Thirdly, to synthesise how both of these designers integrated theories, methods, shapes and services for the construction of architecture as a thermal ambiance. Lastly, to devise a comprehensive review of the evolution of notion of thermal comfort and its architectural affection in Le Corbusier's works from the late-1930s to the early-1960s.

1.3 METHODOLOGY

This research has been built upon historical and bibliographic research methods for the study of both, historic documents and library collections. First of all, I have developed a bibliographical analysis in order to understand the project's main questions in a wider sense. It was mainly carried out among the libraries of the *Fondation Le Corbusier*, the *Cité de l'Architecture et du Patrimoine* and *ENSA Nantes*. Moreover, online research databases have been also consulted at this phase. The majority of the documents analysed have fed the theory and discussion chapters of this report.

Secondly, I have studied the journals and books published at the epoch where the research is focused. The main source has been the research library of the *Bibliothèque Nationale de France*. This phase has sought to contextualize the closer context of Missenard and Le Corbusier and also to construct a full picture of the French engineer, given that apart from the works of Emmanuelle Gallo and Giulia Marino there are no other biographical facts collected. The main search patterns, consequently, have focused on the topics of heating systems, thermal comfort and André Missenard's biography, theoretical and professional facts.

I have also studied specialised journals of architecture and engineering as well as conference proceedings paying attention to thermal comfort, heating systems and Missenard's figure in a French context. At this point it is important to note the general guidelines given by Emmanuelle Gallo (personally and through her works) to approach the history of heating techniques in the twentieth century in the French context and to Missenard's biography.

The type and groups of documents that have been studied are listed below:

- Journals: *L'Architecture d'Aujourd'hui* (1930-1950), *L'Homme et l'Architecture* (1945-1947), *Techniques et Architecture* (1941-1953) et *Œuvres et Maitres d'œuvre* (1945-1954).
- Conferences and Professional meetings: *Annales de l'Institut Technique du Bâtiment et des Travaux Publics* (1949-1957) and *Congrès du Chauffage au Conservatoire des Arts et Métiers* (1933).
- Missenard's books: *Le Conditionnement des Locaux. Conceptions et Réalisations Modernes* (1934), *L'Homme et le Climat* (1937), *Le Chauffage des Habitations du point de vue Physiologique et Hygiénique* (1938), *Cours supérieur de chauffage, ventilation et conditionnement de l'air* (1939), *A la Recherche du Temps et du Rythme* (1940), *La Chaleur Animale* (1946), *Le Chauffage des Habitations* (1947), *A la Recherche de l'Homme* (1954), *Le Chauffage et le Rafraîchissement par Rayonnement* (1959), *Conductivité Thermique des Solides, Liquides, Gaz et de leurs Mélanges* (1965), *Vers Une Homme Meilleur par la Science Expérimentale de l'Homme* (1968) and *Le Chauffage, la Ventilation et le Conditionnement d'air* (1953).

Lastly, I have conducted the archival research at the historical archive of the *Fondation Le Corbusier*. It focused on the search patterns of Missenard (André Missenard and Ets Missenard-Quint), *chauffage* (1937-1960), *ventilation* (1937-1960), *confort, climat (climat and climat artificiel)*, Dusseris (collaborator of Missenard that regularly appears signing letters and projects of the company), *ventilation*, air (air and *air-conditionné*), Pierre Winter and Alexis Carrel. The search patterns have revealed

relationships with projects as well as names of particular people or companies that have also been explored.

These are the groups of documents that have been found in this research:

- Documents:
 - + Courriers: chronologiques, correspondance, dossiers nominatifs (André Missenard, Pierre Winter and Alexis Carrel).
 - + Congrès: CIAM V (juin 1937) and Ascoral (juin 1943).
 - + Carnets: C12, D15, D16, E21, J36 and M54.
 - + Projets: Maisons Jaoul, Grille Climatique, Unité d'habitation Rezé, Maison du Brésil, Couvent Sainte-Marie de la Tourette, Unité d'habitation de Briey-en-forêt, Unité d'habitation Firminy, Musée d'art occidental Tokyo, Centre de calculs électroniques Olivetti.
 - + Microfilms: Maisons Jaoul, Maison du Brésil, Couvent de la Tourette, Unité d'habitation Rezé, Unité d'habitation Briey-en-forêt, Unité d'habitation Firminy.
 - + Photothèque: Unité d'habitation Briey-en-forêt, Unité d'habitation Rezé, Maisons Jaoul, Maison du Brésil.
- Plans: Aérateur, Grille Climatique, Maison du Brésil, Couvent de la Tourette, UH Rezé, Maisons Jaoul, Unité d'habitation de Briey-en-forêt, Unité d'habitation Firminy, Musée d'art occidental Tokyo, Centre de calculs électroniques.
- Bibliothèque personnelle LC: *L'Homme et le Climat*, Missenard 1937, FLC J 416; *A la recherche de l'homme*, Missenard 1954, FLC J 330; *Influence des conditions thermiques ambiantes sur la capacité de travail, la morbidité et la mortalité des ouvriers et la construction des lieux de travail*, Missenard 1943, FLC V 567; *La mécanisation au pouvoir: contribution a l'histoire anonyme* Giedion 1948; *Jour après jour 1893-1944*, Carrel 1948, FLC J 71; *Réflexions sur la conduite de la vie*, Carrel, FLC V2; *L'homme, cet inconnu*, Carrel 1936, FLC J 418; *Contre la vie chère. Les magasins à prix uniques*, de Pierrefeu 1933, FLC V 290.

In addition, several missing documents or references required establishing parallel contacts. It was the case of the *Maison du Brésil*, which involved contacting William Curtis, Bernard Bauchet and Denise Leitao with the aim of clarifying the radiant floor heating system's original and current state.

2 THEORETICAL AND CONCEPTUAL FRAMEWORK

2.1 HEALING AND INVIGORATING ENVIRONMENTS

HEALTH AND HYGIENE IN MODERN ARCHITECTURE

The rise and dissemination of Modernism can be defined by two main events in the history of medicine. The first one was the discovery of microbes, followed by the development of microbiology (1870s) and the identification of the tubercle bacillus by Robert Koch (1882). The last one was Selman Waksman's discovery of streptomycin (1940s), which made treatment methods for tuberculosis simpler. This second period was, furthermore, coincident with the end of the WWII, with the subsequent redirection of the war industry to the construction of modern society.

The scientists' belief in microbes as the origin of illness and epidemics triggered throughout a special attention to the milieu and its curative effects throughout the nineteenth century. In this "Age of the Environmental Hygiene", the main efforts were laid "on environmental factors in the etiology of disease and the emergence of bacteriology and biochemistry as basic sciences" (Grundy and MacKintosh 1957, 29). The rise of public health as a career and the special attention of physician and nurses to the necessity for fresh and clean air as well as to the microbicidal capacity of sunrays came up against the lessons of the Hippocratic treatise *On Airs, Waters and Places*. Throughout the nineteenth century, the sanitary organizations struggled to promote inhabiting practices that included the opening of windows for ventilation (Corbin 2014a, 319) and sunlight access to the apartments. As Florence Nightingale stated: "Direct sunlight, not only daylight, is necessary for speedy recovery" (Nightingale 1863, 17). The built environment accompanied a whole way of life and a total control of living conditions oriented towards healing illness and to preserving health as a way of preventing massive diseases.

All of these historical landmarks must be understood in the wider framework of the nineteenth century, when the interest in the notion of milieu was common in science and culture (Gandolfo 2008). Biologists in the nineteenth century, following the theory of acquired characteristics developed by Jean Baptiste Lamarck (1744-1829), had accorded greater importance to natural and social environments than to heredity (Turda 2010). Even Charles Darwin, who elucidated the theory of natural selection, accepted the role played by environmental factors in the work of evolution.

The French physiologist Claude Bernard informed in his laboratory works his claims about the importance of the *milieu intérieur* on the cellular development of the organism. In his own words: "*Bien loin par conséquent, que l'animal élevé soit indifférent au monde extérieur, il est au contraire dans une étroite et sauvente relation avec lui*" (Bernard and Dastre 1878, 113). Also the writer Emile Zola (1840-1902) exemplified with *Le Roman Expérimental* (1881) a scientific insight in writing in the same direction. He emphasized the centrality of the milieu as a determinative force in human lives. In 1952, Canguilhem also stated the relevance of the milieu with his article "*Le Vivant et son milieu*" (2001):

It is introduced to biology by Lamarck, who was himself inspired by Buffon, though he never used the

term other than in the plural. De Blainville seals this usage. Etienne Geoffroy Saint-Hilaire in 1831 and Comte in 1838 use the term in the singular, in an abstract sense. Balzac opens the gates to literature in 1842, in the preface of the *Comédie Humaine* and it is Taine who first uses it as one of the three analytical principles used to explain history. (Canguilhem and Savage 2001, 7)

The built environment was seen as a key arena for creating a controlled milieu to heal illness and improve public health. Architecture and urbanism became influential for the full control of the human living environments and they were therefore intertwined by a wide group of professionals. The link between tuberculosis and housing conditions in urban working classes also favoured the reformist attempts of several socialist organizations. In France, for example, the architect Emile Trélat, at that time president of the *Société de Médecine Publique et d'Hygiène Professionnelle*, presented the paper "*Cités ouvrières, maisons ouvrières*" (1878), where he stressed the need to provide an improved standard of housing for the rapidly expanding French urban working class. Alongside this, the Garden City movement in England and the Life Reform movement in Germany promoted conditions for social housing that avoided urban density and mixed city with nature.

Since the late-nineteenth century, specialised institutions such as sanatoriums and asylums were promoted in idyllic natural spaces. These early-medicalised architectures were based on functional schemes, forms and constructive conditions strictly established by the hygienist's regulations. They were exemplified in several projects of Tony Garnier for the *Cité Industrielle* (Lyon, 1914), such as the *Hôpital*, the *Centre d'héliothérapie* or the *Ecole verte* but also many others like the *Zonnestraal Sanatorium* (Hilversum, 1926-1928) of Bijvoet and Duiker, the *Finsbury Health Care Centre* (London, 1938) of Berthold Lubetkin or the *Paimio Sanatorium* (Paimio, 1932) of Alvar Aalto.

TROPICAL COLONIALISM: SANITATION AND ACCLIMATISATION

The importance of the milieu for the biological reactions of the human body in human biology was enhanced by the arrival of the European colonists to the Tropics. In particular, the influence of tropical climate and food in the colonists' bodies was largely studied by specialists from the very beginning of the nineteenth century. For instance, it is evidenced in James Johnson's "*The Influence of Tropical Climates on European Constitutions*" (1813), C. P. Lukis and R. J. Blackham's "*Tropical Hygiene for Anglo-Indians and Indians*" (1911).

In the very origin of tropical medicine, this new discipline assumed the acclimatisation of human body to tropical climate and supported the idea of differences between locals and colonialists. In the case of India, Jackson (2014) reveals how the hygiene officer and sanitation inspector were charged with documenting these effects and attempting to improve living conditions. Their outlooks, perceptions and decisions had major consequences for development in tropical cities where death rates far exceeded those of temperate climes. They thought, however, that once the white man was adapted to the local climate, the rates would be similar. As Van der Plaats (2014)

reports, in Australia the acclimatisation strategies understood architecture like a way of climatic regulation to create European indoor conditions for the colonialists

In contrast, the subsequent influence of the Victorian theorists of race and the biological determinism broke the association between racial distinctiveness and climate. They identified the difference and superiority with the biological attributes, which effectively negated questions relating to the viability of white settlement within the world's tropical regions. In Northern Australia, the emerging discourse on tropical architecture was subsequently related to the Australian Institute of Tropical Medicine's interest in theories of racial segregation and Eugenics in addition to preventative medicine and hygiene (van der Plaat 2014).

The theory of biological decay and degeneration, which resulted from the evidences of the occupation of the world's warmer climates by people from cooler latitudes were not only influential for tropical colonialism. On the contrary, it was just an evidence of the effects of climate in human bodies that was openly recalled in the works of eminent physiologists, geographers or engineers until the end of the WWII. Missenard was one of these followers, as he argued: *"L'hérédité d'un home blanc ne lui permet pas, par exemple, de supporter impunément le climat des tropiques ; il y perd, non seulement se qualités physiques, mais aussi son caractère moral, et les climats artificiels doivent pouvoir limiter le mal"* (Missenard 1937, VI).

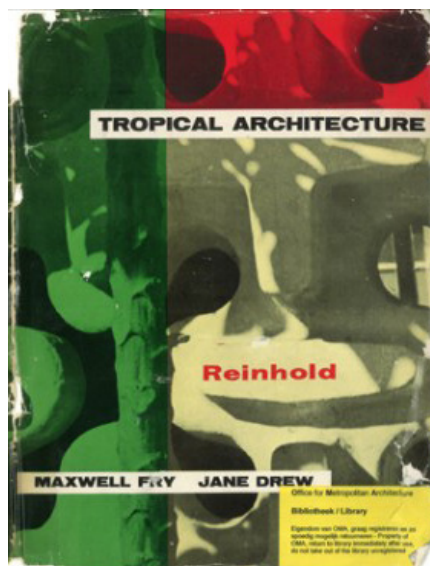


Figure 1. Book Tropical Architecture of Maxwell Fry and Jane Drew, 1956.

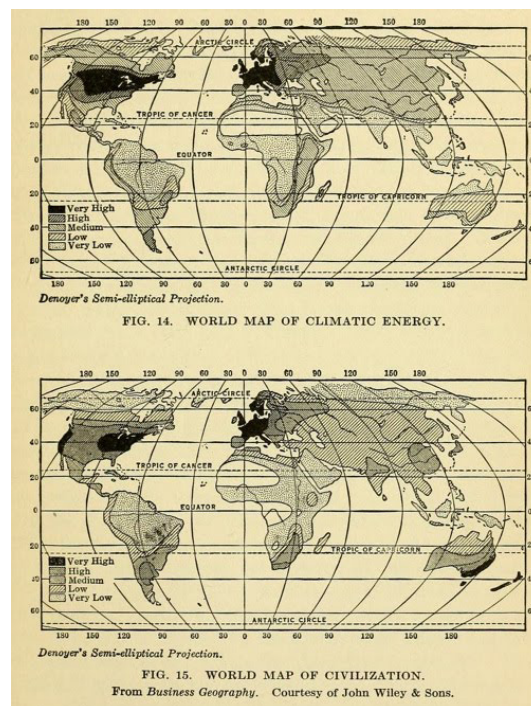


Figure 2. Maps of energy and civilization (Huntington, 1915)

ENVIRONMENTAL DETERMINISM: DEGENERATION AND INVIGORATING

In the late-nineteenth century, health and social reformers were divided between those who explained degeneration in terms of inappropriate social environment and those who saw it as caused by hereditary disposition. As Turda (Turda 2010, 26) notes, the Eugenic thought was mainly related to the latter view, although the relationship

between environment and heredity was not always easy. Karl Pearson argued in *The Problems of Practical Eugenics* that “the attempt to improve the racial fitness of the nation by purely environmental reforms, the removal of child and mother from unhealthy surroundings and the provision for the weak and the suffering has failed in promoting racial efficiency”.

Both cases shared the common idea of a biological, cultural and moral degeneration as a result of uncontrolled nutritional practices and artificial climate exposure. From this angle, Eugenics has to be understood as a part of an intellectual elite that was frequently enveloped by their social and political existence. As Turda (2010, 119) argues, eugenicists “were not separated from the culture they inhabited and the questions they posed about the individual, society and the state, as well as the interpretations they extracted from their empirical data and experiments were shaped by cultural attitudes, social needs and political possibilities”. As a matter of fact, the French biologist and Nobel Prize Alexis Carrel (1873-1944), who was a friend and collaborator of Le Corbusier and André Missenard, was an eugenicist and helped to popularise these ideas:

La science, qui a transformé le monde matériel, nous donne le pouvoir de nous transformer nous-mêmes. Elle nous a révélé le secret des mécanismes de notre vie. Elle nous a montré comment provoquer artificiellement leur activité, comment nous modeler suivant la forme que nous désirons. Grâce à sa connaissance d'elle-même, l'humanité, pour la première fois depuis le début de son histoire, est devenue maîtresse de sa destinée. (Carrel 1935, 257)

Environmental determinism brought together a wide range of professionals, such as physicians, economists and geographers (Ackermann 2002). Their fundamental argument was that aspects related to physical geography, in particular the climate, influenced the psychological mindset of individuals. According to this, culture and individuals' behaviour were directly determined by climatic conditions. These theories established a positivistic view of both European and North-American societies as a comparative reference, which were consequently a reference of biological and moral efficiency. Ellen Churchill Semple (1863-1932), Ellsworth Huntington (1876-1947) or Thomas Griffith Taylor (1880-1963) can be considered early theorists of environmental determinism.

In particular, historians of Eugenics and Comfort commonly highlight the American conservative geographer Ellsworth Huntington as one of the main ideologists of this theory. He stated the bases of the physiological climatology in the influential book *Civilization and Climate* (1915). As Ackerman (2002) reports, he explained human behaviour and achievements in terms of the climatic conditions experienced by each society, accounting thereby for the rise and demise of great civilizations. Current scholars hold him up as a warning of the dangers of “Meteorological Taylorism” (Fleming 1988) and an example of how science was used to legitimate imperialism (Peet 1985), yet within the field of thermal comfort studies the lasting influence of his ideas has largely been overlooked. Huntington's works were acclaimed in America and Europe, becoming a regular correspondent and a reference of Carrel. Moreover, the

geographer's maps, used to argue for climate as a factor in the evolution of each race, were translated to a French audience by Missenard (Missenard 1937; Missenard 1940).

The Eugenics community in France represented a relatively small group of elites predominately composed of physicians, statisticians and public health officials, but also politicians and intellectuals. They did not formally organize into the French Eugenics Society until 1912 that, as a matter of its relevance, was joined by the two French Nobel-Prize winners Carrel and Charles Richet (1850-1935), who openly declared themselves as eugenicists. If the German eugenicists addressed racial hygiene, in the case of France the focus fell under the environmental control of the different growth steps, which was called *puériculture*. This term encompassed everything from baby's wellbeing to preconceptional hygiene, promoting the development of controlled and pure environments: the incubator, the nursery (*crèches*), the kindergarten (*école maternelle*), the open-air school (*écoles de plein-air*) and the garden city.

Understanding evolution as a long running term, the theory of race linked to the environmental determinism claimed a biased but also fluid and malleable viewpoint, which allowed both improvement and degeneration for all races. Depending on the climatic context all human beings could be vigorous or enervated, primitive or civilised. To do so, technical and scientific resources were at the service of the development of the living environments that improved human efficiency in tropical or equatorial climates, which also influenced in cooler latitudes afterwards.

As a consequence of this desire for fully controlled atmospheres, physiologist, engineers and industrialists related their works on environmental determinism to justify the importance of specific contributions in a wider framework. Paramount technical contributions like the air-conditioning were conceived in the early-twentieth century with the double idea of improving the efficiency of both Northern and Southern citizens (Ackermann 2002). Several research works reveal how the air-conditioning industry progressively moulded society's awareness of indoor climate control and home comfort feeling (Rybczynski 1989), or how it changed the way of life of the Southern states of the United States (Arsenault 1984) influencing everything from architecture (Fitch 1975) to sleeping habits (Hailey 2009).

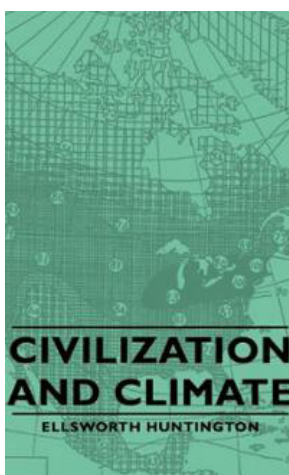


Figure 3. Civilization and Climate. Ellsworth Huntington



Figure 4. Open-air school, M. Lods and E. Beaudoin, Suresnes, 1935.

2.2 ATMOSPHERES FOR EFFICIENCY AND COMFORT

THE DEVELOPMENT OF THE NOTION OF THERMAL COMFORT

In the period 1910-1930, the matters related to thermal comfort, even to the general idea of comfort, were explicitly explained according to local, cultural and climatic characteristics. The scientists conducted qualitative and quantitative research on physiology, not merely based on intuitive statistical observation, but also on more and more complex experiments. Taking advantage of the outcomes of this research, after WWI, the young air-conditioning industry researched the market potential of indoor climate control enhancing its effects on health and productivity.

In the same way as stove and radiator producers of the 1910s-1920s, Carrier's ads in the 1930s gave evidence of their early relationship with this idea. For instance, Carrier reacted to the American 'Dust Bowl' (1930-1936), a phenomenon that brought some of the hottest summers on record to the United States and especially the heatwave of July 1936¹. They promoted slogans such as "No heatwaves here!" (resorting to health and comfort) or "Unconditional surrender" accompanied by a drawing of a heat exhausted officer (resorting to productivity).

This connection of science with industry after the 1930s triggered comfort no longer being considered as a specialization in the field of hygiene. Comfort became a discipline by itself built upon both scientific and technical knowledge. The redefinition of the notion of thermal comfort as coolness and coolness as a necessary condition of daily life required that both winter overheating and summer heat were adapted as risky but curable physical states (Ackermann 2002). It was crucial that comfort was elevated in importance by association not only with health and efficiency, but also with progress and civilization. Thus, Carrier's ads turned into slogans such as "New Carrier Climate Centre" or "Now heat and cool your home with a modern miracle - The Carrier heat pump Weathermaker".



Figure 5. Heating ad system in the 1920s Figure 6. Heated-slab ad in the 1930s



Figure 7. Carrier HVAC ad in the 1930s



Figure 8. Carrier HVAC ad in the 1950s

One of the most important contributors to this process was the British physiologist Sir Leonard Erskine Hill (1866- 1952), who was director of the Department of Applied Physiology at the National Institute for Medical Research From 1914 to 1930. He carried out studies of indoor conditions that identified the more influential factors to promote health in buildings and completely reoriented the study of ventilation since 1911 (Bedford 1952). He focused on the effects of the chemical and physical properties of the air and disproved the old theory stating that respiration of Carbon Dioxide was responsible for discomfort (Roberts 2009).

Professor Hill's works concluded that the human body required to prosper the stimulus of constantly changing environmental conditions (Hobday 2010). To do so he suggested that indoor environments needed to be analogous to the outdoor conditions, namely: cool breezes around the head, the radiant heat of the sun and warm ground to stand on. According to Hill, these conditions could only be reach by using a radiant heat method, "a warm floor and agreeable movement of cool air, the conditions of a sunny spring day out of doors" (Hill 1925, 37).

In his book *Health and Environment* (Hill and Campbell 1925), Hill stated that the central heating could create a monotonous, over-warm and still atmosphere. Such conditions, Hill argued, were contrary to inhabitants' health because they deteriorated the body's capacity to generate heat, which influenced the appetite, the depth of breathing, muscular tone, the vigour of blood circulation and provoked relaxation and sleep. As Hobday (2010) reports, Hill made an important distinction between comfort and health. He asserted that the aim should not be to pamper individuals by removing thermal strains on their lives, but to keep them strong and fit. Hill's premise was that humans have an inherent need to challenge and exercise their thermoregulatory system. The American architect Frank Lloyd Wright (1867-1959) became afterwards an influential supporter of this angle:

The human body is able continually to adjust itself-to and fro. But if you carry these contrasts too far

too often, when you are cooled the heat becomes more unendurable; it becomes hotter and hotter outside as you get cooler and cooler inside... I think it far better to go with the natural climate than try to fix a special artificial climate of your own. Climate means something to man. It means something in relation to one's life in it. Nature makes the body flexible and so the life of the individual invariably becomes adapted to environment and circumstance... I doubt that you can ignore climate completely, by reversal make a climate of your own and get away with it without harm to yourself (Wright 1954, 176).

In the same period, the A.S.H.& V.E² had managed to ensure the enactment of a new 30 cuft/min ventilation standard for New York Schools. This new code ensured that only costly mechanical ventilation would be powerful enough to meet it. The expert in public health Charles-Edward Winslow (1877-1957), who headed the New York State Commission on Ventilation, began an inquiry on human physiology focused on the specific environments of factories, places of public assembly and classrooms. This commission studied young clothed male subjects under three atmospheric conditions (Winslow and Herrington 1949) and their experiments led in the end to the dismissal of claims of the superiority of mechanical ventilation for comfort as well as to the recommendation of lower indoor temperatures (Hill and Campbell 1925). They found no evidence that supported the theory of the temperature's influence on better educational outcomes rather than teaching (Cooper 1998).

Subsequently, the A.S.H.& V.E. started their own laboratory in Pittsburgh to study the interaction of air temperature, humidity and ventilation under controlled conditions. Houghton and Yaglou (1923) introduced a new index of warmth, the Effective Temperature, allowing an understanding of the equivalent warmth of any combination of air temperature, humidity and ventilation rate (Bedford 1936). Together with C.P. Yaglou's work at Harvard from 1925, they sought to establish credible standards of comfort for indoor conditions (Cooper 1998).

The complementary approach of engineers and physicians was reflected in the use of two different experimental methods to assess thermal comfort. The former, based on the use of measuring tools (i.e., the Bedford's *Eupathéoscope*) on mock-ups, inert bodies heated up to 37°C or in-situ measurements in large fabrication halls. The latter, built upon laboratory research conducted in climatic chambers adapted to recreate artificial atmospheres perfectly controlled.

As Addington (2009) wrote, after the 1918–1919 influenza pandemic, engineers and manufacturers were quick to capitalize on the public's concern with cleanliness. They pointed out that the air handler could produce a manufactured weather that produced "the same splendid physical exhilaration that you feel after two-days vacation in the naturally pure air of the mountains"³. In spite of the continued work of open-air enthusiasts such as Winslow and Hill during the following decades to challenge mechanical systems, most of the early ventilation laws remained in place and the air-handler-based system became the standard for conditioning interior environments.

The research in thermal comfort was a field developed in different countries in Europe and America. Namely: Houghten and Yaglou at the ASHVE laboratory (United States); Winslow, Harrington and Gagge at the laboratory of the Foundation John B. Pierce (United States); Bedford at the London School of Hygiene and Tropical Medicine (England); Augusto Giovanardi at the Istituto d'Igiene of the University of Milan (Italy); Missenard in his own company installations (France).

In this background, Missenard was recognized by his contemporaries as the French counterpart of Winslow and nowadays, researchers on the history of techniques and comfort reflect Missenard's practical and theoretical contributions in the 1930s (Cooper 1998; Chappells and Shove 2004; Marino 2014). As it will be duly detailed in the next chapter, the French engineer regularly quoted the contributions of Huntington, Mills, Winslow, Yaglou or Markham in order to place his own work in a wider context.

Physiologists, engineers and industrialists worked closely to shape popular ideas and normalize standards of climatic desirability and indoors comfort. After WWII, the domestication of war industry focused their promise of technology on the house, the family utopia and their standards. Rybczynski (1989) makes the point further that since the 1920s, comfort has changed not only quantitatively but also qualitatively. Technological developments, he argues, have played a special role in shaping the recent history and physical reality of comfort and in turning it into a mass commodity. Thus, cultural ideas like comfort, Rybczynski concludes, have a life that is measured in centuries.

Chappells and Shove (2004) suggest that meanings of comfort are historically malleable and that there are significant differences in what counts as normal in any one culture at any particular time. The implication of innovators and technologies play an important role in making and meeting needs. As Ackerman (2002) reveals, only from this point view we can understand the exponential rise of the air-conditioning industry from the 1940s to nowadays.

What this process finally achieved was the societal assumption of man's capability of controlling indoor climates in order to satisfy his needs. The use of the notion of thermal comfort to define the desirable environment promoted neutral atmospheres where the human body did not suffer any type of thermal strain. In a general way, this early association of the term comfort to modernity was considered as the "self-conscious satisfaction with the relationship between one's body and its immediate physical environment" (Crowley 2001). Therefore, the gap among physiological needs, human perceptions and cultural acceptability or desirability reflects the broad spectrum of what thermal comfort was in fact for modern architects and engineers.

SENSORY PERCEPTION OF MODERN ARCHITECTURE

The emergence of the paradigm of the sensory in Social Sciences in the 1950s and the 1960s (Merleau-Ponty 1945) shifted the notion of comfort. Whereas in the inter-war period it was mainly considered from a physiological viewpoint, after the 1950s both physiological and psychological factors were equated for on similar levels.

As Marino (2014) reports, with the development of cognitive sciences in the late-1950s, the research into the conditions for an optimal material wellbeing abandoned the dimensions of the “sanitarianism” to approach the theoretical presuppositions of ergonomics. Placed at the crossroads of psychology, physiology and occupational medicine, ergonomics searched for improve productivity trough a detailed analysis of the working process.

The notion of comfort was afterwards related to the atmosphere and to multisensory perception. As Howes states, “in the 1960s architects and urban planners were already sensitized to this issue, if only partially, by the works of Marshall McLuhan and E.T. Hall, who introduced the notions of ‘sense-ratio’ and ‘proxemics’” (Howes 2005). Even if started at that period, the theorization of an architecture for the senses, Howes continues, is just a recent phenomenon that is growing around the sensory qualities of the material world and their social significance.

In Pallasmaa’s view, heat and the sense of touch impart an emotional overlay in perception (Pallasmaa 2005, 58). When looking at a painting, he says, we feel the warmth of the water in a bathtub or the moist air of a landscape, but we can also sense the heat of the Sun and the cool breeze. Furthermore, Boon states that other senses like smell, sound or taste are often similarly described in terms of temperature (Ong 2012). The enjoyment of foods or drinks, in particular, is enhanced when consumed at the right temperature but also heat is critical when explaining its appetizing smells.

Current authors like Zumthor and Rahm affirm that in the same way as other sensory experiences, an architectural work generates an indivisible complex of impressions involving a haptic perception of the space (Zumthor 2009; Rahm 2009; Pallasmaa 2005). In this regard, heat has been conditioning our living spaces physically and physiologically from the very origins of architecture.

The space of the home has been widely studied at this angle. As Fernández-Galiano (1991) explains, the significance of the hearth or the stove for the sense of home is related to their symbolic power to fuse archaic images of the life-supporting fire, experiences of personal comfort and symbols of togetherness and social status. As Pallasmaa (1994) notes, in the modern home the hearth has become flattened to an object with a distant and decorative function. Fire itself has been tamed and turned into a framed picture devoid of its essential task of giving warmth.

Not only the home with its confined and controlled ambiance is involved. Siret (2012) observes that understanding sunlight in terms of warmth rather than in terms of daylight recalls the sense of touch in the public space. The sunlight touches our skin producing both a physiological reaction in our bodies and a psychological reaction in our mind. As Siret works reveals (Harzallah and Siret 2010; Siret 2013a; Siret 2013b), the control of solar radiation for adapting it to our needs of daylight, heat and warmth in urbanism and architecture was a main issue in the debates of the modern era. Effectively, we can vividly recall gardens, streets or walls against the angle of the sun, with materials or textures that multiply or mitigate the heat of radiation.

Frank Lloyd Wright, Alvar Aalto and Le Corbusier have been consistently pointed as relevant by the theorists of architecture and the historians of sensory and techniques (Pallasmaa 2005; Fernández-Galiano 1991; Gallo 2006). More modern architects, however, would also be highlighted in a deepest sensory study, such as Richard Neutra, Walter Gropius, Marcel Lods, Jan Duiker or Josep Lluís Sert, among others.

NOTES:

- ¹ National Weather Service Weather Forecast Office, “The Heatwave of July 1936”, consulted on 22 August 2014, <http://www.crh.noaa.gov/arx/events/heatwave36.php>
- ² American Society of Heating & Ventilation Engineers
- ³ “Theatre Makes Own Weather”, 10 September 1926, *St Petersburg Times*, p. 6.

3 ANDRÉ MISSENARD AND THE ARTIFICIAL CLIMATES

3.1 MISSENARD'S BACKGROUND, WORKS AND FILIATIONS

André Missenard (1901-1989) was a French engineer trained in the renowned *Ecole Polytechnique* in Paris. He was an enthusiast of physics that juggled his devotion to higher education and scientific research with his professional practice as an engineer and an industrialist.

In 1926, Missenard joined the company of his father-in-law *Etablissements Quint et Flamant* (Raoult 2007). Joseph Quint was an engineer of *arts-et-métiers* that had previously owned a foundry. Since 1903, he had associated with different engineers to run his industrial company, which managed to develop the first French patent for an industrial agitator in 1933. Missenard's arrival to the firm was aimed at heading up the new branch of heating and air-conditioning. Finally, his progression in the structure deserved him the co-direction in 1949, when the name was changed to *Etablissements Missenard-Quint* (Missenard-Quint 2013).

This *thermicien* of inquiring spirit soon revealed his interest in the study of human body reaction to the environment's physical parameters. The emerging theory of climatic determinism, related to the utopian construction of the *Homme Nouveau*, gave him a broader arena to place his theories for a greater social and cultural relevance. In this regard, the English economist Sydney F. Markham (1897-1975), the geographer Huntington and the physiologist Winslow were usual references of Missenard, which he quoted systematically in books such as *L'Homme et le climat* (Missenard 1937) or *La chaleur animale* (Missenard 1946a). They constituted the theoretical constructs that supported his research on the human thermoregulation and environmental conditioning throughout his career.

Les civilisations naquirent dans le pays où la température naturelle est le plus souvent voisine de la neutralité thermique. Lorsque se répandit l'habitude de chauffer les locaux, les homes places dans des climats naturels plus froids, furent moins désavantagés et même mieux stimulés par les inévitables variations de température [...] plus la latitude augmente, plus les homes soumis à des climats froids sont naturellement plus vigoureux, ce qui augmente leur efficience lorsqu'ils sont places dans les conditions favorables des locaux chauffés.
André Missenard (FNB 1976, 16)

In a closer context, Alexis Carrel was a close friend and a mentor for Missenard. Carrel's book *L'homme, cet inconnu* (Carrel 1935), where he argued in favour of the social and moral consequences of dietetics patterns, was a reference for the engineer to establish wider implications for the environmental conditions where human beings had grown up. They met each other thanks to Carrel's request to Plon editors for writing the foreword of Missenard's *L'Homme et le climat* (Missenard 1980). Afterwards they established a personal and ideological exchange that persisted until Carrel's death in 1944.

Despite the fact that the history of the twentieth century has subsequently placed the physician as a polemic personage in both medical and ideological angles, at that time Carrel was a renowned professional. In 1906 he joined the Rockefeller Foundation in New York, where he developed pioneering vascular suturing techniques that deserved him the Nobel Prize in Medicine in 1912. Charismatic and controversial, Carrel was also a friend and collaborator of Le Corbusier from the late-1930s.

In 1939, Missenard introduced Jean Coutrot to Carrel. Coutrot, who also was a *polytechnicien*, founded the *Centre d'Etudes des Problèmes Humains* whose motto was to develop an "economic humanism" through a collective thinking process (Drouard 1990). The same year Carrel joined Coutrot's centre. On 17 November 1941, the physician transformed it into the *Fondation Française pour l'Etude des Problèmes Humains*, which was linked to the cabinet of the France of Vichy where Carrel served as regent (Reggiani 2007).

From 1939 to 1940, Missenard was mobilised as an artillery officer to the front of Alsace and Lorraine for combatting against the Nazis invaders. He gave evidence of this period in his diaries published in *Combats et retraite en Lorraine 1939-1940* (Missenard 1944). Once he was demobilized, he adhered to Carrel's foundation, becoming its vice-president from 1942 to 1945, when it was transformed into the *Institut National d'Etudes Démographiques (INED)* (Drouard 1990). Missenard was director of the Foundation and responsible for the Department 1 *Biologie de la population*, which was composed of four teams: *biologie de la lignée* (chaired by Docteur Gessain), *natalité* (Fernand Boverat), *habitat* (Jean Merlet) and *recherches biophysiques* (Roger Giblin)⁴. In 1968, Missenard wrote about the ideas and projects that they promoted at this epoch:

Hypothèse déraisonnable, rêve insensé ? Qu'en sait-on puisque l'expérience n'a jamais été tentée ? Je suis fermement convaincu qu'elle réussirait, au moins partiellement, et tout gain dans ce domaine aurait des répercussions humaines considérables. C'est par tous les éléments du milieu -physique, chimique, psychique, social, ...- qu'il faut "cerner" les hommes. Parce que les cours de morale et les sermons ont échoué, a-t-on le droit de douter, alors qu'on ignore tout encore des ressources de la 'terra incognita' de Bergson ou de l'altruisme vital de Guyau, et de ce qu'on pourrait en tirer, par un climat artificiel et une nourriture appropriés, ainsi qu'une ambiance sociale ne mettant pas tout en œuvre pour exaspérer ses instincts les plus bas et les plus asociaux ! (Missenard 1968)

The diversity of his many occupations and his way to deal with knowledge was reflected throughout his life. His career can be analysed in three different but deeply connected activities: teaching; physiology and human science; industrial physics and climatic techniques.

TEACHING

From the early-1930s to the 1970s, Missenard lectured for architecture and engineering students at various academic institutions on the design, construction and physiology of indoor thermal atmospheres. The relevance of his research and their implementation to his professional practice gave him a perfect background for his lectures, which deserved him the recognition of wide range of professionals.

In 1932, he began lecturing in industrial physics for engineering graduates at the *Ecole Supérieure des Travaux Publics*, where he stayed as a professor till 1942. At the same period, the architect Emmanuel Pontremoli (1865-1956) became director of the *Ecole Supérieure des Beaux-Arts* at Paris. In the spirit of creating a stronger cohesion between education and practice, Pontremoli expected to balance academic architectural training with technical and practical lessons on the building process. As Brucculeri (2006) reports, he charged this task to the professor Edouard Arnaud (1864-1943), who was specialised in architectural engineering⁵. He launched new studies on reinforced concrete by François Vitale (1932), ventilation and heating equipment for buildings by Marcel Véron (1933) as well as hygiene and healthiness in housing by Félix Marboutin (1933). This change was celebrated by manufacturers, who thought that French schools of architecture did not devote enough time in their degree programs to technical subjects on heating, ventilation, water supply or other equipment networks (Gallo 2012).

After the departure of the professor Arnaud in 1934, Missenard restarted the lectures on heating and ventilation by supplementing the theoretical courses with visits to particularly interesting technical installations⁶. Pontremoli enhanced Missenard's initiative in parallel to his interest in linking the electricity and lighting lessons with the Public Service Unions of Electricity. The engineer continued lecturing until 1968 as a *Maitre de conférences de l'Ecole Supérieure des Beaux-Arts* in *Thermique des Bâtiments (Isolation, chauffage, ventilation et conditionnement de l'air)*. The manuscripts of his lectures are still preserved at the library of the current *Ecole Nationale des Beaux-Arts*.

In the late-1930s, together with his collaborator Roger Giblin, Missenard compiled all his lessons in a global teaching program published in the *Cours supérieur de chauffage, ventilation et conditionnement de l'air* (Missenard and Giblin 1939). It was presented in four volumes: *Principe et description des installations* (1939); *Étude théorique générale* (1941); *Calcul des projets et des installations* (1943); *Compléments divers* (1947). They were conceived for a progressive and comprehensive study of the thermal phenomena in buildings, although each book was considered as a manual useful for specific professionals. The editor explained this criterion in the foreword of the first book: "*Les différents livres ont, en outre, été conçus de telle manière que leur étude successive ne soit pas une nécessité absolue. La connaissance du premier livre pourra suffire aux architectes. Et les praticiens pourront se servir utilement du Livre III, relative à l'établissement des projets, sans avoir nécessairement étudié en détail le Livre II, dont le caractère théorique est assez poussé [...] Enfin, différents compléments, plus ou moins indépendants les uns des autres, ont été groupés pour constituer le Livre IV*" (Missenard and Giblin 1939).

The last part of Missenard's teaching career was more disparate. From 1956 to 1970, he lectured at the *Ecole de Thermique* of the *Institut Français des Combustibles et de l'Energie*, where he focused on the effects of climate in culture and society. Lastly, he

lectured at the *Ecole Polytechnique*, where he used to be a student, on the vast subject of the human problems in politics and social economics associated to the climate.

PHYSIOLOGY AND HUMAN SCIENCES

In the context of the first half of the twentieth century, the development of the notion of thermal comfort derived in two main scientific trends: the study of the human body thermoregulatory reaction to the environment and the rationalization of human atmospheres according to biological or social parameters. As a result, climate, indoor atmospheres and the human body were interlinked to develop the ideal environment for modern society involving a wide range of professionals, such as physiologists, physics, industrialists, geographers and architects.

Missenard developed his particular approach built upon both points of view. On the one hand, he was a researcher in physiology and physics that tried to understand the human thermoregulatory system and its relation with climate and society. On the other hand, as an industrialist he worked on the heating and ventilation techniques that allowed to create and to control these conditions. As a result, his profile has to be understood judging him as a researcher in physics and human environments with the intellectual inquisitiveness of placing his work in the global framework of the *Homme Nouveau* utopia.

In 1929, together with René Dupuy and Roger Giblin, Missenard developed a new thermosyphon design and calculation procedure, based on creating water coils with different temperatures for mixing outward and returning water. One year later, he proposed the renowned principle of the Resultant Temperature (RT) in order to replace the previously prevailing Effective Temperature. In addition to air temperature, relative humidity and wind velocity, Missenard's RT also considered the influence of wall temperature by radiant transfer in the thermal sensation.

L'impression de chaleur étant intimement liée à la totalité des échanges calorifiques du corps avec l'ambiance, on conçoit qu'un individu puisse ressentir la même impression thermique dans deux enceintes différant par la température de leurs parois, et par la vitesse et la température de l'air. André Missenard (VV.AA. 1935)

In 1932, Missenard oriented his efforts to studying the body's evaporation laws and the resulting thermal losses. He established an evaporation coefficient for the sweat on the skin's surface, presented as a proportion of the thermal convection coefficient. A couple of years later, he patented a thermometer to measure the RT that was called Resultant Dry Thermometer. It was based on a metallic hollow ball of 9 cm diameter painted in black that contained a regular thermometer inside. Besides this, during the same period he also dealt with the theory and practice of heating and cooling by air blowing (Missenard 1946b; FNB 1976).

In 1937, he published the book *L'Homme et le climat* that compiled the research that he had conducted in several fields and interlinked them with a global state-of-the-art of the influence of climate in health and human behaviour, especially in terms of physical and intellectual productivity. His own research and the state-of-the-art were constructs of his new proposal for a comprehensive understanding of environmental techniques

and human physiology. It was at this moment that he coined the term “*Science des climats artificiels* (Science of Artificial Climates)”, that would accompany him throughout his life.

Even if his thought seems to be clear and sure about the physiology of thermal comfort, the engineer was not always as conclusive as it could seem. In 1950, Missenard stated that “*à l’heure actuelle, les conclusions de la science sont encore trop récentes pour être considérées comme la garantie d’une définition exhaustive des conditions physiques*” (Missenard 1950). In an article of 1957, he reported that the “*raisonnements reposant sur des constatations expérimentales, dont on admet l’exactitude jusqu’à preuve du contraire*”, even though he was in “*désaccord complet avec certaines conclusions américaines*” (Missenard 1957a).

The impact of his works in the scientific and engineering communities deserved him the Hermann Rietschel Honorary Gold Medal of the German Federation of Heating and Air-Conditioning Engineers in 1938. From this moment on, he oriented his research to the development and contextualization of the Science of the Artificial Climates by assembling together his experimental and practical works with the contributions of French, American, British, Spanish, Italian and German researchers. His following books reproduced the structure of *L’Homme et le climat*, progressively changing from experimental-theoretical works (such as *Le chauffage des habitations du point de vue physiologique* 1938, *A la recherche du temps et du rythme* 1940 and *La chaleur animale* 1946) to fully theoretical manifests (such as *A la recherche de l’homme* 1954 and *Vers une homme meilleur par la science expérimentale de l’homme* 1968).



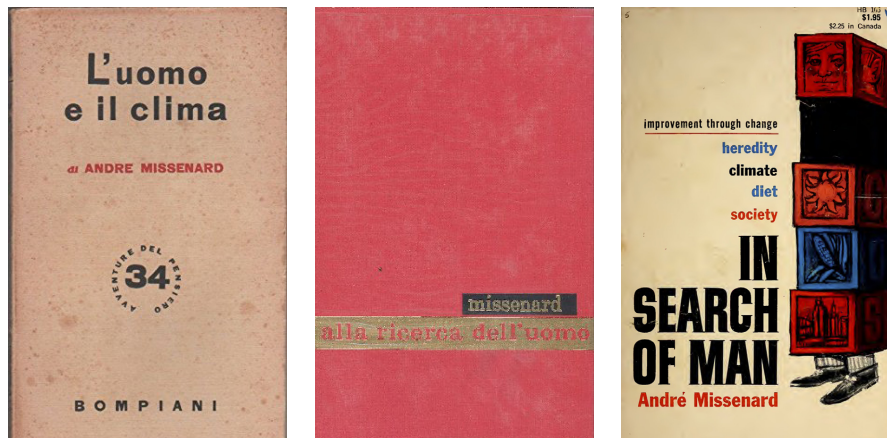


Figure 9. Examples of Missenard's books covers studied in this research.

INDUSTRIAL PHYSICS AND CLIMATIC TECHNIQUES

When Missenard arrived at the *Ets Quint et Flamant* in 1926, the launch of the new branch of central-heating gave him the opportunity of developing a professional practice linked to his research interests. The engineer, nevertheless, was not in the idea of settling a regular company on heating systems like those already existing in France at the time, such as *Gandillot* (radiant floor heating system), *Ets Mortreux* (air convectors), *Sulzer* (central-heating systems), *Ets Neu* (air-conditioning) or *Ateliers Ventil* (ventilation). Missenard's proposal was to distinguish himself from other manufacturers by dealing not only with the equipment but also with his knowledge on thermal comfort and hygiene. His approach to the engineering and manufacturing practice was, consequently, an extension of his many research experiences.

The way that the company introduced itself was evidence of this different approach. In 1935, the *Ets Quint et Flamant* published an advertisement in the special number of heating systems at *l'Architecture d'Aujourd'hui*. The firm did not promote a particular system but an engineering service that created indoor atmospheres, offering procedures to obtain "*Le confort & l'hygiène maxima par le conditionnement des locaux*". As the advertisement noted, their work went beyond the technical installation:

Nous demandons qu'on nous pose des problèmes précis et spéciaux de conditionnement de l'air (cliniques, hôpitaux, écoles, voitures et wagons, etc.). Nous y réaliserons les ambiances les plus favorables à l'organisme des occupants en provoquant, si nécessaire, des recherches médicales pour les problèmes nouveaux. (VV.AA. 1935)

In a similar way, during the 1950s the company published leaflets that enhanced their theoretic-practical approach with the slogan "*Nouvelles techniques des Climats artificiels. Etablissements Missenard-Quint*"⁷. In order to exemplify their experience, they presented their collaboration in the works of modern buildings like the *Unité d'habitation* of Rezé, explaining both heating and ventilation systems. This way of placing their engineering and industrial contributions in the wider framework of Modernism deserved Missenard and his company the professional recognition of engineers and architects, who became

more and more interested in building facilities from not only an engineering angle. Nonetheless, he never forgot the technical branch of the company, which was reinforced with technical manuals such as *Le chauffage des habitations* (1947), *Le chauffage et le rafraîchissement par rayonnement* (1959) or *Conductivité thermique des solides, liquides, gaz et de leurs mélanges* (1965).



Figure 10. Ets Quint Flamant ad (1935)

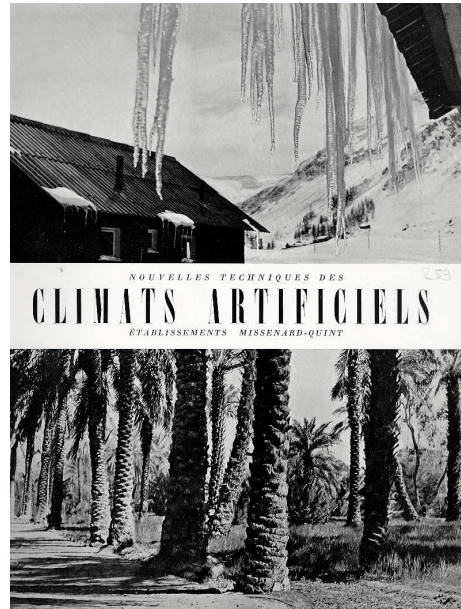


Figure 11. Ets Missenard Quint leaflet (late-1950s)

HEATING SYSTEMS INNOVATIONS

Missenard disagreed with the massive use of air-blowing based techniques, which was not a rarity because other experts like L. Hill, C.E Winslow or C. Rosenqvist supported the same approach. He stated that continuous air movement mixed dust's bacteria with the fresh air, increasing the risk of contagion. In parallel, his physiological research justified the possibility of achieving thermal comfort by controlling mainly the surrounding wall temperature, which involved low air movement. Thus, he promoted the use of radiant heating systems for healthier housing environments, although he also implemented other systems in particular installations.

The engineer's company was not the only one interested in patenting modern radiant heating systems at the time. For instance, in France this method had been installed since 1929 by the firm *Maison Emile Nessi et Fils et Bigeault* (Fougeret 1933) and the well-known patent of *Dériaz* was registered in 1935. *Ets Missenard-Quint* developed a patent for a radiant floor heating system that integrated the water pipes inside a concrete/cement slab. Their innovation was based on reducing the length of the heating coils by adding a thermal insulation strip above the pipe, which balanced temperature distribution on the surface and reduced the cost of the pipe installation. The operating temperature of the system could therefore be 90°C if the pipes were inside of the reinforced-concrete structure, but if they were in the compression slab the water should be 50-60°C (Cadiergues 1952). This procedure was widely called by company members and other collaborators *Système Missenard* (i.a., the patent plan FLC K2.6.296 in 1953⁸).

Apart from Missenard's patent, the *Ets Missenard-Quint* was also allowed by the English firm *Richard Crittall & Co.* to work with their licence of radiant heating panels in France. Documents preserved at the FLC's archive give evidence of the interest of the French in promoting their alliance as a "*Concessionnaire des Brevets Internationaux de Chauffage par Rayonnement. LICENCE CRITTALL*". What is more, the *Ets Missenard-Quint* also permitted *Crittall & Co.* to exploit their patent in all Europe, excluding France. The descriptive report for the heating system of the *Maison du Brésil* reflects this: "*Le chauffage par le sol à température normale et à enrobage hétérogène (brevet MISSEWARD) est exploité en Europe par les Groupement International de la Richard CRITTALL STRALINGSWARMTE [radiant heating]*".

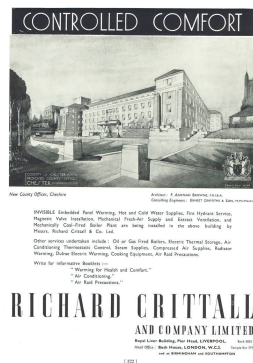


Figure 11. Controlled Comfort by Richard Crittall Company

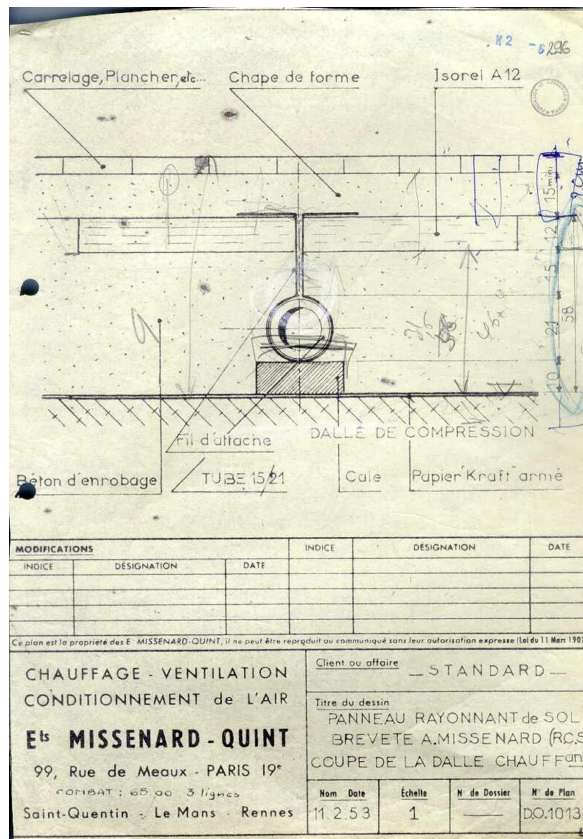


Figure 12. Heated-slab patent by Ets Missenard Quint (FLC K2.6.296)

Crittall's patent described a warm water system originally aimed for schools and sanatoriums. It was based on radiant heating coils in panel format for being fixed to the concrete surface and embedded into the plaster facing. It was firstly patented in 1907 by the professor Barker¹⁰ with the particularity of using small pipes and warm water instead of medium pipes and hot water. Afterwards, *Crittall* bought the patent and appointed representatives across Europe, like *Ets Missenard-Quint* in France. The dissemination of the patent in Europe was also related to their link with some modern architects, who found in this innovative scheme a perfect complement to make the thermal conditioning of open-plan spaces affordable. For instance, Alvar Aalto implemented *Crittall's* radiant heating system in the walls and ceilings of the Vyborg Library (1927-35) as advised by the Finish engineer Carl Rosenqvist, who learnt of the

system during his visits in the early-1930s to *Crittall's* headquarters in London and Paris¹¹. Another well-known example is the *Openluchtschool* in Amsterdam (1928), designed by the architects Jan Duiker and Bernard Bijvoet.

The documentary evidences show that *Ets Missenard-Quint* proposed both systems equally for their projects in collaboration with the *Atelier 35S*. Commonly, the construction company or the budgetary engineers argued in favour of the *Système Missenard*, which was cheaper than *Crittall's* one.

PROFESSIONAL RECOGNITION

In 1935, the French journal *L'Architecture d'Aujourd'hui* paid attention to the greater relevance of the environmental regulation equipment for architecture, devoting a special number entitled *Chauffage et Ventilation*. The publication was a compendium of the French know-how in heating techniques in which several engineers were invited to explain their knowledge and experiences. The volume revealed new details for architects throughout the process: heat production, heat transport, heat use, spaces conditioning, equipment control, *mise-en-œuvre* and a catalogue of works.

Missenard was invited to write the article *L'utilisation de la chaleur* (Missenard 1935a) that explained the physiological basics of the heat transfer and the heating systems operation¹². In addition, he summarized the state-of-art of three important techniques in the European context: *chauffage par convecteurs*, *chauffage par panneaux à basse température* and *chauffage par le sol*. All of them were exemplified with pictures that exposed some of the heating patents available in France at the time, such as *Crittall* and *Dériaz*. He also showed his practical experience in a second article in the last few pages of the journal, where he presented an *Ets Quint & Flamant's* realisation for a Parisian restaurant's air-conditioning system (Missenard 1935b).

Other engineering or industrial firms were represented at the journal either by explaining their realisations or by advertisements: *Carrier* (air-conditioning), *Sulzer* (central heating), *Ets Neu* (air-conditioning), *Mecano* (electric heating) and *Chauffage Gandillot* (floor heating system based on *Dériaz* patent). The journal was the evidence of the emergence of a popular awareness in the quality of housing environments, represented by heating and ventilation systems, which required the involvement of the architects to succeed.

Between the 1930s and the early-1940s, Missenard was the French rapporteur of the *Health Organisation* of the *League of Nations*. Furthermore, he was related to an ad-hoc Committee created with the aim of establishing the principles for the "*Hygiène de l'habitation*". The implications of thermal comfort in housing was a main topic of this committee: "*L'habitation, constituant l'un des facteurs exogènes les plus importants dont dépend le bien-être physique et psychique, doit donc être adaptée aux besoins physiologiques complexes de l'homme quant à la lumière (à la fois sous le rapport de la vue et des effets de la lumière sur le corps humain, aux échanges calorifiques, à la respiration, à la protection contre le bruit, notamment chez les enfants), à la chaleur, à la propreté et aux conditions sanitaires satisfaisantes*"¹³. Missenard contributed with his works and opinions to this organization, where he collaborated with C.E. Winslow, J. Parisot (1882-1967), H. van der Kaa (n. 1881), W. Wilson Jameson (1885-1962) and T. Bedford.

In 1946, Missenard's works in *L'Homme et le climat* inspired an article for an issue about sunlight, air and human body for the journal *L'Homme et l'Architecture*. This journal edited by Le Corbusier's collaborator André Wogenscky, who entrusted Maurice Bismuth with a graphic article entitled *L'air et l'homme* (Bismuth 1946), which seems to be a graphic explanation of Missenard's theories.

In January 1948, the journal *Œuvres et maîtres d'œuvre* published a number entitled *Chauffage-ventilation, conditionnement*. The foreword written by Missenard (Missenard 1948) explained the role of heating, ventilation and conditioning for buildings. Others of Missenard's colleagues like Dupuy and Nessi were contributors in the physical and physiological matters related to the heating equipment. There was also an article about the 'artificial climates' that was written by Bernard Tunzini, who mainly summarized, paraphrased or quoted Missenard's works.

The French journal *Techniques et architecture* dedicated two special issues in 1949 to the topic "*Équipement thermique*". Missenard did not take part in the first issue, even if the authors of the articles copiously quoted him. The engineer only wrote the foreword of a second issue, which was entitled "*Civilization et climat*", arguing in favour of the necessity of artificial climates for social and biological development.

In 1949, the *Institute Technique du Bâtiment et des Travaux Publics* began its thematic meetings again. The first series of conferences on 8th February and 9th February 1950 addressed the research and experiences of the heating and ventilation techniques. Not by chance, Missenard chaired the two days of presentations and debates.

At the same time, the *Comité Scientifique et Technique de l'Industrie du Chauffage et de la Ventilation* (Costic), which existed since 1906, chose Missenard as new president to conduct its restructuration. In 1950, he appointed his colleague the *polytechnicien* Roger Cadiergues (1923-2013) as new director.

On 8th, 9th and 10th May 1951, Missenard also chaired the second series of the ITBTP's conferences. They were devoted to a vast range of heating and thermal conditioning topics, such as: the air entrance in air-conditioned spaces; the resultant temperature thermometer; thermal research in buildings and public works laboratories; the state-of-the-art of the research on heating and ventilation in foreign countries; issues arisen by the installation and operation of central heating systems; thermodynamic heating systems; the choice of the type and the general characteristics for heating facilities that are well-adapted to climate and building program; heating systems based on overheated water under pressure.¹⁴

On 27 May 1952, Missenard chaired another series of conferences focused on developing an updated state-of-the-art of the radiant heating systems in the United States, Germany, Italy and France (VV.AA. 1952). He repeated the same experience three more times in 1953, 1955 and 1957 extending the invited countries. These three international cycles deserved Missenard recognition outside of France. The foreword of the English translation of *A la recherche de l'homme*, which was translated by Lawrence G. Blochman¹⁵ and published in New York (Missenard 1957b), gives evidence of this:

In a fascinating and reasoned discussion of the factors of human nature, Dr. Missenard shows how we can make radical changes in heredity, diet, climate and society—changes that will mold the man of the future. Demonstrating how intervention in nature can

be extremely harmful, the distinguished scientist makes an impassioned call for an intelligent control over the present drift of human change. (Missenard 1957b, 1)

3.2 THE SCIENCE OF THE ARTIFICIAL CLIMATES

MISSENARD'S NOTION OF ARTIFICIAL CLIMATE

In an article from 1934, Missenard highlighted the contributions of French scientists that since two years before had conducted research in the desirable composition of indoor environments and the steps to avoid contagious diseases transmitted through the air. With an approach still based on hygienism, he argued in favour of extending these contributions not only to obtain healthy environments for hospitals, but also to achieve an optimised atmospheric composition to protect human life in a more general angle. In this regard, Missenard considered that the entire corpus of knowledge and techniques for the indoor environment management according to their effect on the human body must be considered an independent field. In Missenard's words: "*la réalisation des conditions atmosphériques et calorifiques désirables pour le corps humain, constituent une technique qui se différencie suffisamment du chauffage et de la ventilation pour que l'on se soit avisé de lui donner un nom*" (Missenard 1934, 1).

Due to the complexity of this new area he searched for a new name. He dismissed the use of Anglophone neologisms such as *climatisation* (weatherizing) or *conditionnement de l'air* (air-conditioning) for not being comprehensive enough with all the phenomenon's complexity. He suggested, therefore, calling it *Conditionnement sanitaire des locaux* or *Conditionnement des locaux*. According to Missenard, it recognised the importance of working in parallel on the environmental conditions where humans are immersed as well as on the techniques that allow for the control of indoor environments.

In 1937, his book *L'homme et le climat* presented a state-of-the-art on climatic determinism built upon studies of geographers, climatologists and physiologists. It was the framework that placed his technical contributions in a broader interest, allowing him to introduce a new and more ambitious proposal in the last chapters: the Science of the Artificial Climates¹⁶. Conceived as an evolution of the heating and air-conditioning techniques, Missenard presented the Artificial Climates as a general organization of the human environments that paid attention to human body requirements for both healthy and sick people.

Il convient de s'élever contre la tendance actuelle à réaliser des climats artificiels d'une façon désordonnée. Cette technique doit rendre de grands services, mais pour les homes sains, ce doit être, surtout, en combattant les effets fâcheux des conditions artificielles ou arbitraires dans lesquelles la civilisation matérielle, ou la colonisation, place l'organisme [...] Quand les connaissances générales seront beaucoup plus précises et beaucoup plus sûres, peut-être pourra-t-

on envisage de réaliser des conditions artificielles pour remplacer le climat naturel, même sain, et obtenir ainsi des individus certains efforts ou certaines performances exceptionnelles. Mais nous n'en sommes malheureusement pas encore là. (Missenard 1937, 253)

As the previous quote reveals, his short-term aims involved researching the biological disorders brought upon by the rise of the human being exposed to uncontrolled artificial climates in buildings such as factories, theatres or stores. In contrast, his long-term objectives aimed, on the one hand at controlling and materialising the healing effect of the environments by controlling the indoor climatic factors. On the other hand, he promoted the Science of Artificial Climates in order to overcome human biological shortcomings through a process of environmental training.

Three years later, with the book *A la recherche du temps et du rythme* (Missenard 1940), Missenard continued arguing for the artificial climates in two ways. Firstly, by comparing the differences between the inhabitants of urban and rural contexts, exposed to artificial and natural climates respectively. Lastly, by developing the ideal climates for children's education and for workers' productivity, according to international physiological research. Both angles nourished the knowledge that supported his theory.

In 1946, Missenard published *La chaleur animale* (Missenard 1946a), where he argued once again against the uncontrolled use of the artificial climates by showing the results of laboratory environmental research on animals. He aimed to understand these negative effects just as an evidence of the influence of artificial environments in animal biology and to suggest how a rational use could take advantage of these effects to improve human biology. As he said: « *le conditionnement climatique peut venir au secours des homes que la civilisation mécanique place dans des conditions anormales. L'artifice au secours de l'artifice* » (Missenard 1940, 239).

In 1968, Missenard continued arguing for the artificial climates in *Vers Une Homme Meilleur par la Science Expérimentale de l'Homme* (Missenard 1968). The title of the book inevitably recalls Le Corbusier's *Vers une architecture* (1923), but is also related with the fully theoretical approach that the engineer claimed in this publication. This time, he defined the aims of the Science of Artificial Climates:

Elle se propose de réaliser dans les locaux les conditions d'ambiance les plus favorables aux hommes, en particulier à la formation physique et psychique des enfants. Si les techniques de chauffage sont éprouvées depuis plus d'un demi-siècle, l'aspect humain du problème n'est étudié que depuis quelques décennies. Certaines questions essentielles ont déjà reçu une réponse apparemment satisfaisante. D'autres ne pourront être abordées que lorsque la science de l'esprit aura fait suffisamment de progrès. (Missenard 1968, 353)

In order to justify his proposal, Missenard used a socio-cultural evolutionism that presented the Science of Artificial Climates as a logical step in humanity's progression. As he said, since the very first steps of the human existence, the quest for an ambiance

that does not cause the feelings of being too cold or too warm had been a natural challenge for human beings as warm-blooded animals. According to Missenard, the fire, heaters, central heating and air-conditioning had been creating and modifying the human atmospheres based on the single fact of the air temperature (Missenard 1947, 5). Consequently, the artificial climates were needed because, as all his references had shown, it was obvious that the air temperature was not the only influential parameter for thermal comfort and human health. In fact, this is the same reasoning that Le Corbusier used to support the urban scheme of the *Ville Contemporaine* in 1922 (Le Corbusier and Jeanneret 1974, 1:35) or the *brise-soleil* shading system in 1938 (Le Corbusier 1977, 4:103).

CLIMATE, AMBIANCE AND MILIEU IN MISSENARD'S THOUGHT

THE SEVERAL PARALLELISMS TO THE NOTION OF ARTIFICIAL CLIMATE

Missenard's aim of placing the human beings in controlled environments with ideal conditions involved a particular approach to the notions of *climat* and *ambiance*. The attention to the notion of milieu, as aforementioned, was common in different fields of the Modern period, so it is important to understand how Missenard used these parallel terms.

In the article "*Le conditionnement des locaux*" (Missenard 1934), the engineer used the term *ambiance* to speak about the building's indoor environments. He used as a synonym of *ambiance* the terms *milieu* and *atmosphère* but not the term *climate*. They were adopted for explaining either physiological or physical descriptions of the environmental conditions.

His notion of *ambiance* was based on a physical parameterization of the environments according to their effects on human biology. In this sense, he suggested the necessity of distinguishing between two sorts of ambiances. Firstly, those oriented for sick people that could be medicalised environments for doing *cures climatériques*, as one more step towards hygienism's heritage. Secondly, the climates for healthy people and rootless people not adapted to the climatic conditions of the place where they are living, which had no medical meaning but following the idea of creating therapeutic atmospheres. He doubted, nevertheless, if the physical conditions of these ambiances should be similar for both of them.

Ces ambiances seront-elles, comme nous le supposons actuellement, les mêmes pour les êtres sains et les malades ? C'est improbable, car, a priori, il n'y a aucune raison pour ne pas rechercher une médication par le milieu aussi bien que par voie ingestive ou cutanée. (Missenard 1934, 12)

In *L'homme et le climat* (Missenard 1937) the engineer added two new terms to talk about the same phenomenon: *climat* (climate) and *temps* (weather). Both notions were usually related to natural and outdoors phenomena, although Missenard referred to indoors and manufactured environments. The adoption of these terms is, on the one hand, a reaction to the researches on climate influences in human biology that he used to support his research's global framework. On the other hand, the use of *climate* for indoors involved a complex viewpoint, which involved an understanding of the indoor

ambiance as live and changeable in all its parameters, like the outdoors climate. This idea became consistent at the end of the book, where he enhanced the study of indoor environments assuming the same complexity that was linked to the atmospheric, social, or biological studies on the climate.

Missenard's works on the thermoregulatory reaction of the human body in the 1930s revealed to him the notion *Ambiances équivalentes* (Missenard 1940, 29). In order to foresee the human perception of a particular environment, he developed the perceptual index of the *Température résultante* that combined the effects of air moisture, air movement, air temperature and radiant temperature. Consequently, Missenard stated, this index could be the same in two ambiances with different air temperatures, so it was possible to find equivalent environments in terms of perception that were physically constituted in a different way. This idea oriented his manner of dealing with conditioning techniques and with the heat-transfer strategy, which he conceived from the angle of the inhabitant thermal reaction by balancing the four parameters according to his aims.

Also in 1940, the engineer dealt with more complex notions of climate that were ongoing in the potential of climatic control to induce therapeutic and behavioral effects in the inhabitants. For instance, he developed the *climats complémentaires* (Missenard 1940, 204), which he considered such as temporal exposure of the body to different climates (e.g., in holiday period). Besides this, he reworked the already existing *climatothérapie* from a scientific angle (Missenard 1940, 204), a healing method built upon temporal or permanent relocations of patients in regions with favourable climates. Lastly, he proposed three different climates according to their degree of human body stimulation. In his own words:

Le climat civilisé, urbain en particulier, dévient de plus en plus stimulant sous tous les latitudes. Or, les climats très stimulants accélèrent la formation [...] elle permet à l'enfant et à l'adolescent d'enregistrer beaucoup de choses, soit par éducation, soit par observation personnelle. Certes, les climats stimulants, accélérant le temps physiologiques, accroîtront la production des homes ayant subi sous d'autres cieux une lente et, partant, riche formation. (Missenard 1940, 239)

Although all the previous explanations are evidence of his deterministic approach, Missenard assumed that the environment where the human body was plunged was broader than these physical or biological definitions. He suggested that there was something beyond the study of already known parameters like temperature, humidity, pressure, light or wind. Missenard considered that "*il est certain qu'il existe des facteurs ignores, analogues aux vitamines en nutrition, et qui jouent un rôle important dans le développement de l'organisme*" (Missenard 1940, 238).

Missenard's text reveal that from the very beginning he focused on the challenge of improving the quality of the living environments in order to evolve human physiology. In this regard, his approach was to place humans in the original conditions where their bodies were shaped, as he said: *"pour la grand majorité des hommes acclimatés leur habitat, la solution la plus rationnelle, quoique apparemment paradoxale, serait probablement de modifier le moins possible le climat naturel"* (Missenard 1937, 233). Nonetheless, he opened his laboratory viewpoint assuming that civilisation had deeply changed human biological needs to obtain maximum efficiency in physical or intellectual work. Thus, he advised a resultant temperature of 17-18°C, what meant 15-16°C of air temperature with 50% of relative humidity and low air velocity.

En tous cas, il est absolument indispensable de limiter supérieurement la température en hiver et d'éviter qu'elle ne dépasse, pour les être sains, 16 à 17° résultants. (Missenard 1937, 235)

The engineer also suggested preventing indoor constant temperatures and thermal homogeneity. He supported that recovering a continual exposure in daily life to thermal strains would train human thermoregulatory system and would make it more resistant. He suggested the use of transitional spaces, like corridors or halls, to establish these thermal gradients and to avoid high thermal changes between the inside and the outside. As he said: *"Pour fixer les idées, on pourra prévoir le chauffage des pièces à occupation normale à 17 et 18°C (soit environ 15 ou 16°C résultants), alors que ces pièces intermédiaires ne seront chauffées qu'à 12 ou 13°C"* (Missenard 1937, 234). These contrasts for the thermoregulation training, he said, had to be controlled and could not be higher than 8 °C (Missenard 1938, 16).

La civilisation requiert une plus grande souplesse d'adaptation aux climats artificiels et naturels que celle nécessaire aux homes primitifs. Or, cette même civilisation atrophie les moyens de défense de l'homme moderne, car sa thermorégulation n'est pas n'est plus entraînée à compenser de brusques variations du métabolisme [...] la réalisation, à l'intérieur des locaux, d'une température constant flattant la paresse naturelle, supprime les efforts adaptatifs pendant la plus grande partie de la journée. (Missenard 1937, 5)

Car le progrès technique permet de maintenir une température intérieure constante avec une grande précision, alors que les anciens foyers domestiques et, plus encore, les antiques cheminées provoquaient de très sensibles variations de la température. Et, ces variations sont nécessaires au maintien de l'entraînement de la thermorégulation. (Missenard 1938, 16)

En bref il faut lutter contre la monotonie du milieu dans son acception le plus large. De même qu'il faut manger les choses le plus diverses, il faut subir les milieux physiques le plus variés, ne serait-ce, à défaut de plus grand déplacement, qu'en changeant de chambre dans une même maison. (Missenard 1940, 240)

The thermoregulation training was a constant in his theoretical books for a long time, although at the very end of his career Missenard recognised that the stimulant capacity of an indoor climate had never found enough scientific support.

Huntington, Winslow et moi-même avons bien défini le climat stimulant caractérisé par de brusques variations de températures - sortes de coups de fouet thermique - mais notre opinion résulte d'observations trop peu rigoureuses. (Missenard 1968, 319)

Missenard was not the only one supporting this idea. Some of his collaborators at the ITBTP conferences or the Costic argued in favour as well.

J'ai déjà signalé notre distinction entre sensation générale de chaleur et sensation de fraîcheur ou d'invigoration, d'une part et de stagnation ou d'énerverment, d'autre part [...] sans modification il n'y a pas stimulation [...] Des données plus quantitatives sont évidemment nécessaires pour que les ingénieurs de Chauffage et Ventilation puissent établir leurs projets avec la certitude de fournir une ambiance invigorante. (Bedford 1951)

C'est là un problème difficile, sur lequel les idées ne paraissent pas très claires et que les anglais ont introduit par la notion de 'freshness' que nous appellerons 'qualité stimulante' d'une ambiance. (Cadiergues 1952, 20)

Recognizing the complexity of the artificial climates, all these recommendations were not permanent for everyone and everywhere but they had to be adapted to the activity developed in the space. He suggested that indoor temperatures had to be altered according to the outdoor temperature oscillations in order not to produce big differences between both the spaces. To do so, *Ets Missenard-Quint* developed a 'sensing system' that monitored outside facts and regulated the boiler temperature according to this. For instance, Missenard stated that for an outdoor temperature of 35°C, inside temperature should be 29°C and for a temperature of 30°C, inside should be 22°C (Missenard 1937, 235). Besides, he recognized that, apart from the deformation of the human skills for physiological thermoregulation, the body needed to be protected from excessive meteorological changes. In his own words:

La température désirable [...] va s'abaissant au fur et à mesure que le travail physique dévient plus

important jusqu'à 8°C, et peut-être même moins pour un travail intense. (Missenard 1947, 10)
On sait que les bases physiologiques admises dans la technique des climats artificiels limitent à 7 ou 8°C maximum la différence de température résultante entre l'intérieur et l'extérieur. (Missenard 1959, 109)

APPROACH TO THERMAL COMFORT

The early research into the human body's thermoregulatory reaction was the support for Missenard's studies in the early-1930s. These works characterized the ambient conditions needed to achieve thermal comfort, however this notion had a different signification for Missenard than for other engineers or industrialists. From a physiological angle, he assumed that thermal comfort was the feeling of well-being that accompanied a respite in the continuous thermal exchange between the human body and its environment. As he said, it necessarily involved a thermal neutrality that was directly related to the evaluation of heat transfer taking into account body parameters (metabolism, clothing and activity) and environmental ones (air temperature, radiant temperature, air humidity and air velocity). He deemed this process as a result of our warm-blooded animals' nature:

'Les premiers hommes, velus et ignorants du feu, devaient se cantonner sous des climats aimables [...] Car la recherche d'une ambiance en suscitant aucune sensation de froid ou de chaleur excessive est un instinct profond qui commande toute la vie des animaux à sang chaud - les homéothermes' (Missenard 1947, 5)

In the late-1920s and early-1930s, the American methods in thermal comfort research and many other scientific studies were based on isolated climatic chambers (Ackermann 2002). In brief, this method mainly dealt with the pure physiological reaction of the human body, leaving social or cultural issues on one side. Missenard followed this way of laboratory research. His approach to thermal comfort tried to isolate the physiological approach from what was culturally understood as thermal comfort. He supported that the cultural understanding was the result of an uncontrolled application of artificial climates by the use of heating and air-conditioning techniques, which led to the human body's acclimatisation to indoor conditions and its consequent decline.

As it can be seen in the references chapters of his publications, his main interests were focused on the physiological and geographic studies that aimed to set an idea of thermal comfort as a result of the body reactions and the site's climatic conditions, which did not have cultural implications. The idea lying behind was a cultural asepticization of thermal comfort in order to recover the human biological definition of well-being far away from the technological deformations that has been created during the previous century.

À une époque où l'on envisage de réaliser, artificiellement, tous les climats, il convient donc d'attirer l'attention sur le danger et la responsabilité que comporte la généralisation, sans précautions, de ces conditions artificielles maintenant, en permanence, ce qu'on estime être le confort idéal. (Missenard 1937, 6)

Faut-il noter, une fois de plus, que toutes ces études sont empreintes de matérialisme et concernent plus le confort physique et l'efficacité corporelle que celle de l'esprit et le comportement caractériel ? (Missenard 1968, 319)

The engineer supported this thought by recalling the 'biological night' effect defined by German hygienists as a consequence of sunlight filtering through a pane of glass, which modified sunlight conditions reducing dramatically the ultraviolet radiation. Hence, the human body was forced to change its internal biological reactions to adapt to the situation, which resulted in new illness. For instance, a solution to this issue was promoted during the 1920s by the use of window patents that allowed the pass-through of UVA rays, like the patent Vitaglass (Sadar 2008).

Missenard's proposal was based on the main idea of placing *"les humains dans les conditions les plus favorables à leur santé et à leur activité. En bref, de les 'conforter' dans le sens original et non adultéré de 'confort'"* (FNB 1976, 17). The influence of researchers like Huntington triggered in Missenard's thought the belief that with the environmental control techniques that he proposed, they would improve human biology. For him, these techniques could protect the human body from delicate moments and, therefore, that would lead to a prolongation of the average lifespan and a rise of the fertility rate. Consequently, in his last works he did not aspire to achieve the thermal neutrality, but to a more complex notion of comfort.

Aussi pourrait-on parler d'une 'neutralité esthétique' comparable à la 'neutralité thermique' des physiologistes, provoquant une impression de confort par l'absence de réaction de défense contre la chaleur ou le froid. [...] le sentiment esthétique est un aspect de la loi physiologique du moindre effort, les états d'équilibre étant les plus agréables : équilibre thermique avec l'ambiance climatique, équilibre psychique quand rien ne heurte notre goût et nos aspirations artistiques. (Missenard 1968, 15)

The engineer idealistic approach to thermal comfort can be understood as a part of a general scientific and cultural trend that asserted that modern man had "retained unaltered the bodily constitution, physiological reactions and emotional drives which he has inherited from his Palaeolithic ancestor. Yet he lives in mechanized, air-conditioned and regimented world radically different from the one in which he evolved" (Dubos 1965).

NOTES:

- ⁴ As Drouard (1990) reports, four other departments were established: Alexis Carrel directed the dept. II 'Biologie de l'enfance et de l'adolescence' ; Jean Lombard directed the dept. III 'bio-typologie' with the teams of 'bio-typologie' and ' psychophysiologie' ; the doctor Gros directed the dept. IV 'travail', with the teams of 'travail' and 'biologie des métiers' ; Henri Guivier headed the dept. V 'production et economie rurale', with the teams of 'production' et 'economie rurale' ; François Perroux directed the dept. VI, composed by the teams of 'enquêtes sociales', enquetes finacieres', 'enquetes economiques, 'enquetes juridiques', 'assurances' and 'problèmes administratifs'.
- ⁵ Edouard Arnaud was an engineer who trained at the Ecole Centrale at Paris and the Ecole des Beaux-arts. Afterwards he lectured at the same EC in building technology and finally he also taught at the Ecole des Beaux-arts at Paris (1920-1929).
- ⁶ Archives Nationales, Paris (AN), Series AJ/52 Ecole des beaux-arts: AJ/52/979 Technical courses and conferences.
- ⁷ Ets Missenard-Quint, "Nouvelles techniques des Climats artificielles", n.d., FLC Q1.15.259.
- ⁸ Ets Missenard-Quint, "Panneau Rayonnant de Sol. Brevete A. Missenard (R.C.S.). Coupe de la dalle chauffante", 11 February 1953, FLC K2.6.296.
- ⁹ Guy Morel Ets Missenard-Quint, "Nantes Rezé BM/SD", 27 February 1953, FLC N4.1.38
- ¹⁰ Granted Patent No. 28477.
- ¹¹ He published his impressions of the visits of the new system in a local journal.
- ¹² He introduces himself as ex-student of the **Ecole Polytechnique**, Professor of the **Ecole Spéciale des Travaux Publics** and delegated administrator of Ets Quint et Flamant. He says nothing about his work in the **Ecole Supérieure des Beaux-Arts**.
- ¹³ Olsen, O., League of Nations, Health Organisation d'hygiène, "Etudes sur l'habitation urbaine", 31 juillet 1935, Archives League of Nations, Geneva, C.H./Hab. Urb. 1.
- ¹⁴ All the conferences were published in the **Annales of the Institute Technique du Bâtiment et des Travaux Publics** from the number 14 (october 1951) to the number 21 (february 1952).
- ¹⁵ Lawrence G. Blochman (1900-75) was an American detective story writer and translator who was born in a French Jewish origin family in San Diego.
- ¹⁶ Up to 1937 he had recognised the artificial condition of the indoor environments but I have not found any reference to the term climat artificiel until the publication of *L'Homme et le Climat* in 1937.

4 LE CORBUSIER AND ANDRÉ MISSENARD: THE CONSTRUCTION OF THE ARTIFICIAL CLIMATES

4.1 LE CORBUSIER AND MISSENARD INTERFERENCES

LE CORBUSIER'S EARLY APPROACH TO THERMAL COMFORT

Before meeting Missenard and going in depth into the core of the Science of the Artificial Climates, a variety of Le Corbusier's collaborators introduced him to the topic. The research at the FLC's archive reveals three main contacts interested on it: Pierre Winter (1891-1952), Alexis Carrel and François de Pierrefeu (1891-1959).

Doctor Winter was a close friend and neighbour of Le Corbusier for a long time¹⁷. Firstly, at 20 Rue Jacob, where Le Corbusier was living from 1917 to 1934, most recently at the 24 rue Nungesser et Coli, where Le Corbusier persuaded the doctor to buy an apartment (Sbriglio 1996).

During the early-1920s, Le Corbusier invited Winter to write three articles in his journal *L'Esprit Nouveau*. These articles glimpsed the doctor's early approach to the physiological education of the body through environmental control: *Sports* (n.14), *Le corps nouveau* (n.15) and *Sports* (n.16). Le Corbusier invited the doctor afterwards to become a member of the editorial committee of the journal *Plans* (1931-32), where the architect was almost never involved (McLeod 1985). Once *Plans* ceased publication, almost all the direction committee founded the journal *Préludes* (1933-1936), a magazine that was ideologically connected to the *Parti Fasciste Révolutionnaire*, in which Winter was a member.

As a consequence of his swimming accident in St Tropez (1938), Le Corbusier met doctor Carrel and he benefited from his experimental wound treatment. This was the beginning of a personal and intellectual exchange that is evidenced in the letters preserved at the FLC's archive. Furthermore, the architect owned, in his personal collection, a 1936 edition of *L'Homme, cet inconnu* (Carrel 1935)¹⁸. Fox Weber (2008, 401) suggests that Le Corbusier subscribed to every word of the physician's book and he described himself in perfect agreement. Particularly in regard with the effects of comfort and human body strains, Le Corbusier explained Carrel's viewpoint in a letter to his mother:

Comfort annihilates the human race. There must be struggles. So don't take difficulties (whatever they may be) as catastrophes, but rather as good hygiene. It's what makes life possible. For if the contrary point of view prevails, everything seems merely a disaster.

We have philosophized with Carrel down to the last issue -the search for what is best for mankind and we are in perfect agreement: the power to create, to intervene, to act is our lifeblood. Otherwise, deterioration. Carrel will work with us. Le Corbusier¹⁹ cf. (Fox Weber 2008, 401)

Missenard was an admirer of Carrel's work and his colleague at the *Fondation Française pour l'Étude des Problèmes Humaines*. As he revealed in an ulterior mail, it was Carrel who introduced him to Le Corbusier in 1942 at the offices of the Foundation. They were placed at 20 Rue de la Baume (Paris VIIIe), in the Rockefeller Foundation's building.

In 1937, Winter was invited to give a lecture at the CIAM V "On Dwelling and Recovery" in Paris. The original manuscript of the lecture, which is preserved at the FLC's archive, was entitled "*Logis et Loisirs*"²⁰. He addressed the relation of urban and architectural environments with the human body's minimal necessities. Actually, his awareness about the troubles of an artificial approach to comfort seems to be really similar to those that Missenard had published during the same year in *L'Homme et le climat*. Winter's words give evidence of his viewpoint against comfort and arguing for returning human beings to nature:

L'homme dans les villes, succombant actuellement aux excès et aux désordres de ses propres inventions techniques, peut succomber aussi aux effets nocifs d'un confort artificiel. Vous allez le bien chauffer, lui donner un air parfaitement conditionné, une lumière artificielle copiant physiquement et chimiquement celle du soleil, une eau filtrée, des aliments bien cuits, il mourra. Il lui manquera ces 'fluides vitalisant invisibles' [...] notre rôle aujourd'hui est de lui restituer la nature, de l'y réintégrer. Pierre Winter²¹

In the same way as Missenard did, Winter's text revealed an approach to comfort based on finding the pure biological reaction of the human body, with the aim of recovering the environmental conditions that originally shaped it. The text also dealt with sunlight from a biological viewpoint, which was a main characteristic of Le Corbusier's thought, as we can see in the documents of the *Ville Radieuse*.

L'être humain n'est qu'un transformateur d'énergie solaire, la vie n'est qu'une circulation de cette énergie, la lumière est un de nos aliments fondamentaux [...] Dans les climats tempérés, plus vous donnerez de lumière, plus vous aurez raison [...] Il faut renoncer définitivement à l'orientation Nord'²²

'Pratiquement deux points vous intéressent tout particulièrement : 1°) l'utilisation du pan de verre, 2°) la lumière solaire doit-elle être donnée directement de plein fouet, ou diffuse, indirecte ? [...] Il existe des verres perméables au UV et IR utilise dans certains jardins zoologiques, encore très coûteux. Ce sont ceux qu'il est souhaitable d'utiliser [...] Lumière directe ? Oui, à petites doses [...] Se souvenir qu'il faut recevoir dans les logis autant que le climat naturel peut en donner,

jamais de maladie par carence de lumière si la dose de lumière indirecte est suffisante. Pierre Winter²³

Le Corbusier's friendship with Winter also brought him into contact with the construction engineer François de Pierrefeu in the early-1930s. He also was a member of the editorial committee of *Plans, Prélude* and *Homme réel*, as well as Le Corbusier's technical and economic advisor for the Algiers' works.

Several years later, de Pierrefeu became a regular collaborator of Carrel and Missenard in Vichy, which coincided with Le Corbusier (15 January 1941 - 1 July 1942). Together they wrote *La Maison des Hommes* (Le Corbusier and de Pierrefeu 1942), a work that Missenard celebrated, imposing it as a manual for the *Equipe d'Habitation* of the *Fondation française pour l'étude des problèmes humains*²⁴.

EPISTOLARY EXCHANGE: THE PERSONAL LETTERS BETWEEN LE CORBUSIER AND MISSENARD (1942-1965)

The FLC archive preserves documentary evidences of the epistolary exchange between Le Corbusier and André Missenard. It is composed of 22 letters addressed from 5 November 1942 to 30 January 1965. Most of the documents have been found in the nominative file entitled André Missenard, though others are under the signatures "*Ouvrage: La Maison des Hommes*", "*Conférences*", or "*Courriers chronologiques*".

On 5 November 1942²⁵, Missenard sent a formal mail to Le Corbusier, which was actually addressed to the offices of *Editions Plon* and forwarded to the *Atelier 35S* afterwards. The goal of the letter was to manifest his gratefulness after receiving an architect's delivery with the book *La Maison des Hommes*, which he had published the same year. Missenard considered the book's lessons relevant because they pointed to understanding the elementary human needs such as organizing guidelines. In his own words: "*la civilisation devrait être organisée en vu de satisfaire aux lois essentielles de la vie et non pas dans une ignorance totale des besoins élémentaires de l'homme*"²⁶. The engineer added that he would impose the study of the book on the entire *Equipe d'Habitation* of the *Fondation*.

Several months later, on 11 February 1943²⁷, Missenard wrote a new letter with the aim of transmitting to the architect the comments of the Direction Committee of the *Fondation Française pour l'Etude des Problèmes Humaines* concerning Le Corbusier's draft for a lecture on 19th February. The engineer advised to avoid references to Alger or any other North African city due to the latest issues of this region²⁸. To do so, he suggested to explain the projects as case study designs located in theoretical sites without names.

On 15 March 1950²⁹, Missenard sent a letter to the *Atelier 35S* in response to a note of Le Corbusier calling on him in order to discuss the indoors thermal conditioning of the United Nations headquarters in New York. Missenard not only accepted the challenge, he also claimed his interest in preserving a rigorous scientific approach to the environmental techniques of this project. Lastly, he suggested introducing Le Corbusier to the new collaborator of his Parisian office René Dusseris, an old student of the *Ecole Polytechnique*.

The next mail was dated 3th December 1951³⁰, just after Le Corbusier's arrival from his journey to India. He asked for the engineer advice due to the challenge that entailed this big commission in a different climate. The architect also expressed his intention of

developing a method to generate works that could operate in any particular set of climatic conditions. Thus, he claimed the need for exploring new ways for regulating architectural environments outside of the rigorous European regulations. In Le Corbusier's words, "*impliquent ses décisions à prendre concernant les lois de l'hygiène (de tout autre nature que nos réglementations conformistes et fruits de tous les compromis)*". He insisted on the necessity of discussing about this aim.

Le Corbusier sent a second letter on 6th December³¹ that seems to follow an intermediate meeting. He confirmed that he would send a questionnaire with their doubts in order to be answered with yes / no / or a new proposal sketch. In the meanwhile, the architect wanted to ask for the Punjab's authorization to make Missenard a payment of 50000 francs against his professional fees "*pour les premières conférences que nous aurons*".

This letter was followed by Missenard's answer on 12th December, where he asked for the aforementioned questionnaire and showed his enthusiasm by proposing to arrange a meeting to explain the answers in person. The engineer highlighted the necessity of linking efforts to obtain the best results possible using the *Ets Missenard-Quint's* systems in the climatic conditions of the Punjab capital. The remaining letters, related to the *Grille Climatique*, were between Iannis Xenakis and Missenard, so they are fully explained in the section of Professional Collaborations.

On 15 July 1952³², the engineer sent a new letter to Le Corbusier. He had been informed by Dusseris (*Ets Missenard-Quint*) and Le Marchand (*Atelier 35S*) of the *Atelier 35S* consultation for the heating system of two houses (the *Maisons Jaoul*), where the engineer suggested using a radiant floor heating system, which was less expensive than the traditional one (see chapter Collaborations). Besides, he showed interest in the progression of the Indian projects and the results of the "*dispositions que nous avons étudiées ensemble*"³³.

Missenard's question was not answered until 8th October, when Le Corbusier expressed his apologies for not giving news about the project and he attached a payment check for his professional fees. Missenard's response, dated 16th October³⁴, reflected his gratefulness for the check but he desired to keep updated of the evolutions of their *Grille Climatique* concept. To do so, the engineer informed of his availability for any kind of complementary help or information without involving new payment.

The contact was lost until 11 March 1954³⁵, when Missenard sent a letter attaching his new book *A la recherche de l'homme*. The letter recalled the moment when they met in 1942 in the company of Alexis Carrel at Rue de la Baume. Likely, the engineer alluded to the 20 Rue de la Baume, where the offices of the *Fondation Française pour l'Étude des Problèmes Humaines* (20 Rue de la Baume, Paris VIIIe) were placed at the Rockefeller Foundation's building. Six days later on 17th March³⁶, Le Corbusier sent a letter of gratitude for the book and showed his interest in the topic.

Once again, the personal contact seems to be lost until 29 January 1960³⁷, when Le Corbusier's secretary expressed his gratitude for Missenard's letter on 26th January³⁸. She confirmed an appointment with Le Corbusier on 10th February at 15:30.

On 12 January 1961³⁹, Missenard sent a mail to Le Corbusier in order to introduce his son Michel Missenard, who had been recently named co-director of the company. On 17th October⁴⁰, Missenard signed a standard letter to inform of the departure of Dusseris

from the Parisian offices of *Ets Missenard-Quint* and *Société Termiq* on 1st December. The engineer Pierre Crotté would replace him until they found a permanent substitute.

On 16 January 1962⁴¹, Le Corbusier sent a letter to Missenard in order to thank him for the gift of the book "*Les grands travaux de l'humanité*"⁴², where he was quoted. The architect, however, was critical of this publication and he sent his comments to the engineer. Firstly, regarding the *Eiffel Tower*, he remarked that he had met Eiffel personally. According to the *UN Secretariat*, Le Corbusier detailed that he had been the director of the project, a fact that he thought was implicitly recognised in the text. Regarding the Brazilian works presented, he pointed himself as the promoter of Brazil's architectural revolution, starting with the project for the *Ministry of Education and Health* at Rio de Janeiro in 1936. At this point the architect enhanced that his buildings triggered an architecture whose main aim was "*Eclairer, aérer et contrôler le soleil*". Consequently he recalled his contribution to the *mur neutralisant* and criticised *Saint-Gobain* due to its derive to the curtain-wall. An example of this sort of proposals was, Le Corbusier stated, his works in Chandigarh.

As colophon, Le Corbusier hesitated in publishing the research on the climatology and physiology of architecture and urbanism that he had been developing for the previous forty years. In this context he recognised a partial collaboration of Missenard to his works and asked him to contribute to the publication along with other specialised colleagues on the topic.

Missenard answered to the architect on 31st January⁴³ expressing his gratitude for the comments, although he remarked that Le Corbusier's contributions to mankind had enough tribute in the text. The engineer continued enhancing the architect's revolutionary works by praising his tenacity and by regretting that they could not collaborate as much as Le Corbusier desired. At the end of the letter, he offered his personal collaboration for the editorial project and he suggested the engineer P.T.T. Conturie as specialist in acoustics for buildings. Apparently, Le Corbusier was establishing contacts in this aim at the same time, as it reveals a photocopy of the last part of the letter⁴⁴ where he noted: "*Important. Que faire avec Jose Bernard pour ne pas le froisser ? Pour Gardien*".

On 14 May 1963⁴⁵, Missenard personally informed Le Corbusier of Crotté's departure from his Parisian office. After this change, he decided to be in charge of the office once again.

The last two mails found at the FLC's archive are dated 30 January 1965⁴⁶. Both of them concern the design of the New Year Greetings Card (*Carte des vœux*) of the *Ets Missenard-Quint* and *Termiq* for the year 1965.

LE CORBUSIER'S PERSONAL LIBRARY

A general analysis of Le Corbusier's personal library through the exhaustive catalogue published in *Le Corbusier et le livre* (Dercelles, Marzá, and Quetglas 2005), allows for the identification of several references related to human biology and the control of indoor climates.

First of all, the architect owned Siegfried Gideon's *La mécanisation au pouvoir: contribution a l'histoire anonyme* (Giedion 1948). The secretary of the CIAM, turned in this book historiography to everyday things in order to report the full mechanization of society. If at that time the publication did not receive a favourable response from the

professional community, nowadays it is widely recognized by cultural studies. Le Corbusier, nonetheless, did not note down particular notes in its pages. At this point, it seems paradoxical that the architect did not own the well-known *Technics and Civilization* (Mumford 1934) of the American historian and sociologist Lewis Mumford.

Three books of Alexis Carrel have been found at the library. Two editions bought after Carrel's death and without notes, *Jour après jour 1893-1944* (FLC J 71) and *Réflexions sur la conduite de la vie* (FLC V2)⁴⁷. The third of Carrel's works is the bestseller *L'homme, cet inconnu* (1935) in an edition of 1936 (FLC J 418), which was a main reference on Eugenics. Le Corbusier wrote copious notes in the margins of the book, apart from a drawing on the back cover.

A book of François de Pierrefeu has also been found. It was entitled *Contre la vie chère. Les magasins à prix uniques* (FLC V 290) and it was published in 1933⁴⁸. As the catalogue authors report, there are almost no notes in this book.

Lastly, Le Corbusier owned three books of André Missenard. A report of 1943 for the Centre of Superior Studies entitled "*Influence des conditions thermiques ambiantes sur la capacité de travail, la morbidité et la mortalité des ouvriers et la construction des lieux de travail*" (FLC V 567), the book of 1954 *A la Recherche de l'Homme* (FLC J 330), both of them without notes⁴⁹ and *L'Homme et le climat* of 1937 (FLC J 416). The third book, which seems to be his first contact with Missenard's thought, is riddled with notes.

LE CORBUSIER'S COPY OF *L'HOMME ET LE CLIMAT*

In 1937 Missenard published the book *L'Homme et le climat* in which he put together the states-of-the-art of physiological research on animal thermoregulation and the geographical research supporting environmental determinism along with his own research on thermal comfort. The book was translated to German (1936) and Italian (1940)⁵⁰, where the scientific and engineering community were more permeable to his works.

The FLC's archive preserves an exemplar as a part of the personal library of Le Corbusier. It is the first edition of the book, dated 1937, but there is no evidence of the purchase date. Nonetheless, the copious notes in the pages' margins in relation to the *Ville Radieuse* and the *Air Exact* point to the period of the late-1930s. Bearing in mind the relationship with their mutual friends, it is reasonable to suppose that the architect read the book just after its publication⁵¹.

The first element noticed in the book is that Le Corbusier wrote an alternative index, which linked Missenard's texts with some of his theories and works. It was a summary of two pages listing where he found any kind of relation with main concepts of his thought, such as *V-R Ville Radieuse* (5 times), *Soleil* (4 times), *Mur neutralisant* (3 times), *Air exact* (twice), *Lumière*, *Ambiance*, *Chauffage*, *Confort* or *Conditions nature* (once).

The numerous notes referred to the Sun proved Le Corbusier's interest in finding a physiological support for his radiant (*radieuse*) architecture, which optimized inhabitants' exposure to solar rays. In this sense, he underlined an assertion of Missenard paying attention to the effects on inhabitants' health of the wrong orientation of houses and streets in an urban context, which the engineer considered as negative as the decrease of ultraviolet radiation due to atmospheric pollution (p. 90). The architect also marked the lines where Missenard argued in favour of sunlight exposure for health in terms of vitamin-C and bactericide effects (p. 92) and therefore, solar accessibility in

housing was crucial for him (p. 98, 99 and 237). Both questions were enhanced by the architect due to their relationship to the *Ville Radiuse*, remembering that sunlight exposure was not only advisable in a social or aesthetical way, but especially in biological terms.

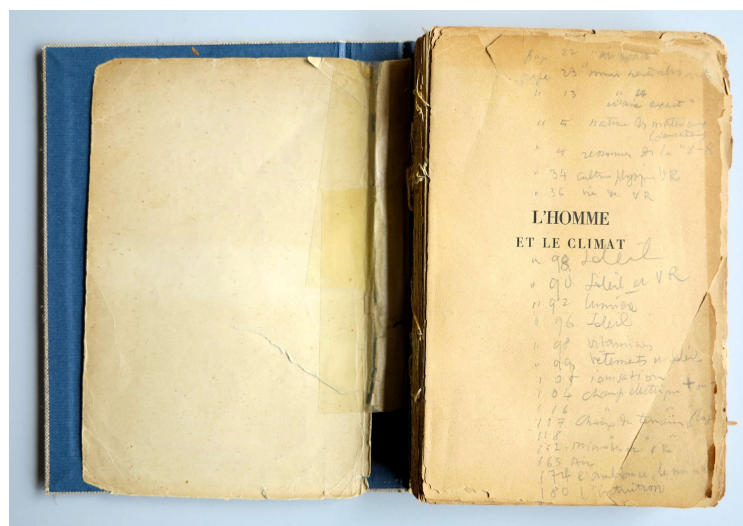
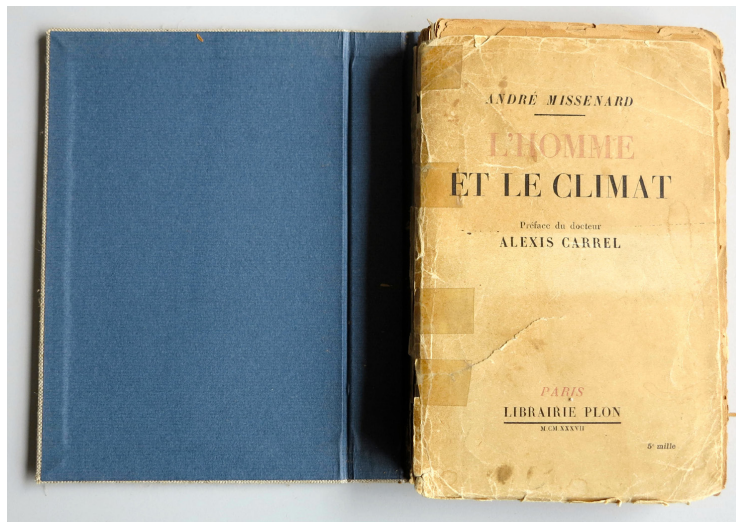


Figure 13. Le Corbusier's copy of *L'Homme et le climat*

Air and ambiance constitute the second main issue underlined by Le Corbusier, in particular he appeared to be interested in the artificial control of indoor environments. He related his preceding creation of the 1920s, the *Air exact*, with Misenard's assertions of the ideal indoor conditions according to physiological studies. The scheme proposed by Le Corbusier supported the approach of the closed building where the interior air was completely tempered, purified and renewed by the aid of mechanical devices.

As Fernandez (2011) and Urbano-Gutiérrez (2012) have stated, the prototype's airtightness would lead to heating expenses and to filtering of polluted air. Le Corbusier recalled five times the *Air exact* at the margins of the book, addressed to removing air bacteria as a way for disinfecting indoor atmospheres. His sketches for the *Air exact* represented a standard indoor temperature of 18°C for every single building, which was

also coincident with the range temperatures preconized by Missenard of 16-18°C (p. 207). The architect previously wrote in his publication *Ville Radieuse*: "*fabrique toute l'année de l'air exact, dépoussiéré, désinfecté, exactement humidifié et porté à la température constante de 18°C environ*" (Le Corbusier 1935, 42).

Le Corbusier's notes seem to agree with Missenard's approach of fully controlled ambiances, even when he assigned a medicinal role to the air suggesting not only controlling temperatures, but also vaccinating through the air (p.236). This assertion, underlined by the architect, was also accompanied by his note "*Air conditionnée. Voici déjà une bonne solution*". This approach agreed with his previous texts for the *Ville Radieuse*:

Avec la respiration exacte, les réglementations édilitaires d'hygiène sont inemployables. Le logis peut devenir autre : muni des joies essentielles. Nous ignorons -nous et le public- la matérialité bienfaisante de l'air vivant traversant le logis, en circuit. Je place mon homme dans ce milieu nouveau : il est souriant, fort, sain. La maladie subit une défaite écrasante (Le Corbusier 1935, 43).

A third point approached by Le Corbusier was the *Culture physique* of the *Ville Radieuse*. The engineer suggested modifying inhabitants' in order to train their immunologic and thermoregulatory systems (p. 34-36). Consequently, he argued against the increasing suppression of the physique effort promoted with the idea of comfort (p. 192), an idea that was also underlined by the architect and that was linked with Carrel's thought.

Another point marked by Le Corbusier was the relation of the climate and environment with creativity and inspiration. He firstly underlined Missenard's statement about the link of the inspiration with the cosmic world (p. 184) and he noted: "*personnellement je ne crois à ce réussite que par intermittence, quand je suis 'luné'. Je suis implacablement poussé à me mettre au travail (crayon et couleurs)*". He followed in the next page: "*En chemin de fer : bruit, rythme, bonasse fugace des images, des paysages. Depuis du contact subit avec la nature, lois de nature, bramasse intense des concepts*" (p. 185).

An idea that was polemic for Le Corbusier, which was stated all across the book, was the relation of geographical, social and cultural connections with climatic determinism. Among them, the need for dealing with the consequences of the bad use of artificial climates with artificial solutions, the high suicide rate in black emigrants to North-America (climatic rootlessness), or the decrease of the reproduction rate in populations living in urban environments. For instance, regarding the suicides rates the architect noted: "*Je vois plutôt que c'est la nostalgie du soleil et l'horreur des slums dans la pluie et le froid*" (p. 190). Also representative is the comment "*discernons les buts !*" (p. 218 and 219) that accompanies the texts about maturity, race, reproduction and so forth.

Finally, Le Corbusier found in this book the inspiration for his subsequent article "*Rétablir les Conditions Nature*" (Le Corbusier 1957). At first, he noted a thought on the *Ville Radieuse* and its power to promote active life, recalling the aspiration to physiologically invigorate environments for humankind, as he said: "*Bon ! comme guidance. Revenir à l'état sauvage et dormir dans une caverne ? Ou, alors, créer les*

compensations néanmoins, par un confortement de vie active, vannée, anti-sédentaire. Conditions V-R ???" (p. 229). At last, he underlined the assertion of Missenard arguing for replacing inhabitants in their natural climate through the use of artificial conditions. He wrote down in the margin: "*réaliser les conditions nature*" (p.253).

The variety of notes that have been found in the book give evidence of the common substrate that grounded both Le Corbusier's and Missenard's thinking. *L'Homme et le climat* appears to be understood by the architect as a confirmation of the actual power of his buildings to contribute to the *Homme Nouveau* project through environmental regulation.

LE CORBUSIER, THE ATELIER 35S AND THE ETS MISSENARD-QUINT

Beyond their professional collaboration, the documents preserved at the FLC's archive prove a close relationship between Le Corbusier, his *Atelier 35S* and Missenard's firm. On the one hand, it have been found a variety of documents related to particular requests of the *Atelier 35S* to the *Ets Missenard-Quint*. On the other hand, a number of documents reveal the interest of both companies in promote their common interest on modern architecture.

PERSONAL REQUESTS

A first group of documents refers to Le Corbusier's intention or necessity for improving the heating system of their office at 35 Rue de Sevres. This process started on 14 January 1955⁵², when Wogenscky sent a mail to Morel of *Ets Missenard-Quint* asking for a project to change the heating system. The origin of this necessity has not been found in the research. It is not coincident with a reform period of the office and the internal notes of the collaborators cannot be fully consulted. The weather chronicles, however, show the three cold waves of the winter of 1954 in France, when the low temperatures (e.g., -13°C Paris or -21°C Mulhouse) came together with cold winds. Specifically, this event has been remembered for the alarm message of the Abbé Pierre (1912-2007)⁵³, which evidenced the population's awareness of this issue.

The engineers' proposal for the heating system was received at the *Atelier 35S* on 13th July. Subsequently, Wogenscky wrote on 21st July⁵⁴ to Tancreze in order to thank him for their work, but also to tell him that the budget was out of their reach. As he said: "*Il dépasse de très loin nôtres possibilités financières actuelles*"⁵⁵. Nonetheless, they remained motivated to improve the heating system because on 6th September⁵⁶ Wogenscky sent a new letter to Dusseris. He insisted on the cost of their previous proposal and he requested a new one that improved their current heating system, but respecting a budgetary limitation from 100000 to 200000 francs.

After this contact, there is no further evidence of the final project adopted, even though a letter on 11th December 1957⁵⁷ confirms that the works were done. Le Corbusier and Andreini complained to Dusseris for the troubles of humidity and condensation around the chimney since the change of the heating system. In particular, they stated, these troubles appeared from the very beginning, which meant 24 months. Thus, we can conclude that finally the works were done between November and December 1955. They finish, moreover, by complaining because during this period they begged them to solve this issue several times without a practical result. Consequently they decided to write this letter.

The second group of letters refers to his personal apartment at 24 Nungesser et Coli in Paris and takes place in the same period as the previous exchange. On 21 January 1955⁵⁸, Gardien wrote to Dusseris asking for a technician for the valves adjustment in the heating system of his personal apartment.

More than three years after, on 15th July 1958⁵⁹ Dusseris answered to Le Corbusier suggesting two different proposals to place a fan in his apartment: "1) ventilateur en applique contre la cheminée. 2) ventilateur supporté par trois tiges scellées dans la cloison entre la cheminée et la cloison". That means that he wanted to install a fan in the living room of the apartment. On 21st July⁶⁰ he answered to Dusseris accepting the wall-fan proposal on the chimney's wall and he urged the engineer to do it as soon as possible. The request of Le Corbusier seems not to be a reaction to climatic conditions but a personal search for comfort. In fact, the climatic chronicle of 1957 and 1958 in Paris revealed abnormal cool and rainy summers, with average temperatures 1° colder than the climatic normes for 1921-1958⁶¹.

COMPANIES INVOLVEMENT

In 1954, when André Wogenscky (1916-2004) was in charge of the *Atelier 35S*, Missenard sent a mail⁶² where he appeared to have a personal respect for him. Even if they had never met, the engineer explained that he had heard as much about Wogenscky that he felt him as a friend. At the same time he confirmed his joining of the *Mouvement Villes Radieuses* that the architect coordinated⁶³. Only a few days later, Wogenscky sent a gratitude letter⁶⁴ for joining the organization and for the delivery of his last book *A la recherche de l'homme*.

When Wogenscky wrote his book *Architecture Active* (1972), he paid special attention to the role of the envelope to mediate with the climate in order to build quality indoor atmospheres. He directly used the name *Climat Artificiel* to define the physical and perceptual conditions of air, light and sound, which had to be adapted to the body's requirements in terms of heat, light and humidity. Thus, even if the letters preserved at the FLC do not reflect a personal relation of Missenard and Wogenscky, he was receptive to his theories. As he stated:

Le bain de juste température. Il faut que notre peau évapore et qu'elle perde des calories. Mais pas trop. Juste réglage de température et d'humidité, et de mouvements d'air, et de rayonnements. L'architecture est créatrice de climats artificiels très agissants sur notre santé. (Wogenscky 1972, 27)

In 1955, the book *Le Corbusier Architecte de Bonheur* was launched. It collected texts, plans and photographs of the design and construction of the *Unité d'habitation* in Rezé-les-Nantes, recently inaugurated at the time. The idea lying behind this publication was to promote the fact that this type of modern and experimental architectures could be also built with the limited budgets of the HLM (*Habitations à Loyer Moderé*).

At its last pages, the book collected the advertisements of all the construction companies that were involved in this experience. In this regard, the *Ets Missenard-Quint's* advertisement took advantage of the avant-gardist character of Le Corbusier's work in order to enhance their experience on innovative heating and ventilation

systems: *“Une expérience centenaire au service des techniques modernes”* (Le Corbusier 1955).

The same approach was used for the leaflets of the *Ets Missenard-Quint* in the mid-1950s. The application file of 1957 for the *Unité d’habitation* in Briey-en-Forêt (see chapter Professional Collaborations) contains a publicity leaflet entitled *“Quelques Références (de 1928 à 1954)”*⁶⁵. Three leaflets are preserved in this file: one for radiant heating systems (ceiling and floor)⁶⁶, which uses the *Unité d’habitation* in Rezé-les-Nantes as an example of realization; another that enhances the company experience in radiant floor heating systems by comparing the entire surface where they had implemented their systems to the surface of Reims; and a third one where there is only the slogan *“Nouvelles techniques des Climats artificiels. Etablissements Missenard-Quint”*⁶⁷ written.

NOTES:

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- ¹⁷ The doctor Pierre Winter writes five articles before the publication of Missenard’s *L’Homme et le Climat* in 1937 related to its topics to some extent:
- Pierre Winter, "Sports", *L’Esprit nouveau* 14 (1922): 1675-1677
 - Pierre Winter, "Le corps nouveau", *L’Esprit nouveau* 15 (1922): 1755-1758
 - Pierre Winter, "Sports", *L’Esprit nouveau* 16 (1922): 1951-1952
 - Pierre Winter, "Pour une science de l’homme", *L’Homme réel* 1 (1934): 37-42
 - Pierre Winter, "Les lois de la nature", *L’Homme réel* 5 (1934): 88-93
- ¹⁸ This book is also present at the personal library of the Fondation Le Corbusier. Cf. FLC J 418
- ¹⁹ Le Corbusier, letter to his mother, 18 December 1939, FLC R2.1.165.
- ²⁰ Pierre Winter, "Logis et Loisirs," June 1937, FLC D2.11.567
- ²¹ Winter, "Logis et Loisirs," 5.
- ²² Winter, "Logis et Loisirs," 6.
- ²³ Winter, "Logis et Loisirs," 7.
- ²⁴ François Pierrefeu has contact with Le Corbusier for long-time. Firstly, as a part of the editorial committee of the magazine *Plans* (1930-1932) and afterwards in their continuation in the journal *Prélude* (1932-1936). This task is shared with Hubert Lagardelle, Le Corbusier, Charles Trochu and Pierre Winter. Pierrefeu stays in Vichy until the end of the regime.
- ²⁵ André Missenard, letter to Le Corbusier (through Librairie Plon), 5 November 1942, FLC B3.3.603
- ²⁶ André Missenard, letter to Le Corbusier (through Librairie Plon), 5 November 1942, FLC B3.3.603
- ²⁷ André Missenard, letter to Le Corbusier, 11 February 1943, FLC A2.18.23
- ²⁸ In the period 1942-43, North African countries are supported by the Americans against the Vichy regime in order to achieve their independency.
- ²⁹ André Missenard, letter to Le Corbusier, 15 March 1950, FLC I3.8.96.
- ³⁰ Le Corbusier, letter to André Missenard, 3 December 1951, FLC E2.16.14.
- ³¹ Le Corbusier, letter to André Missenard, 6 December 1951, FLC E2.16.15.
- ³² André Missenard, letter to Le Corbusier, 15 July 1952, FLC E2.16.18.
- ³³ André Missenard, letter to Le Corbusier, 15 July 1952, FLC E2.16.18.
- ³⁴ André Missenard, letter to Le Corbusier, 16 October 1952, FLC E2.16.20.
- ³⁵ André Missenard, letter to Le Corbusier, 11 March 1952, FLC E2.16.21.
- ³⁶ Le Corbusier, letter to André Missenard, 17 March 1954, FLC E2.16.22.
- ³⁷ Le Corbusier, letter to André Missenard, 29 January 1960, FLC G1.17.48.
- ³⁸ Apparently, this letter is not at the FLC archive or it is not correctly archived.
- ³⁹ Missenard, letter to Le Corbusier, 12 January 1961, FLC E2.16.23.
- ⁴⁰ Missenard, letter to Le Corbusier, 17 October 1961, FLC E2.16.24.
- ⁴¹ Le Corbusier, letter to André Missenard, 16 January 1962, FLC E2.16.25.
- ⁴² They speak about the book: Manceron, Claude, Jacques Boudet, René Hardy and Jules Salvador Moch. 1961. *Les grands travaux de l’humanité*. Paris: Éditions du Pont-Royal.

- 43 André Missenard, letter to Le Corbusier, 31 January 1962, FLC E2.16.26.
- 44 André Missenard, letter to Le Corbusier, 31 January 1962, FLC E2.16.27.
- 45 André Missenard, letter to Le Corbusier, 14 May 1963, FLC E2.16.29.
- 46 Le Corbusier, letter to André Missenard, 30 January 1965, FLC E2.16.30 and 31.
- 47 Carrel, Alexis. *Jour après jour 1893-1944*. Paris: Plon, 1956; Carrel, Alexis. *Réflexions sur la conduite de la vie*. Paris: Plon, 1962.
- 48 Pierrefeu, François de. *Contre la vie chère. Les magasins à prix uniques*. s.l. : s.n., 1933.
- 49 Missenard, A. *A la recherche de l'homme*. Strasbourg: Lib. Istra, 1954; Missenard, A. *Influence des conditions thermiques ambiantes sur la capacité de travail, la morbidité et la mortalité des ouvriers et la construction des lieux de travail*, s.l.: Centre d'Etudes Supérieures, 1943.
- 50 André Missenard, *Der Mensch und Seine Klimatische Umwelt* (Stuttgart: Dt. Verl.-Anst, 1937).
André Missenard, *L'uomo e il clima* (Milano: Bompiani, 1940).
- 51 The transcription of Le Corbusier's handwritten notes quoted in this chapter has been done by the researcher.
- 52 A. Wogenscky and F. Gardien, letter to G. Morel (Ets Missenard-Quint), 14 Janvier 1955, FLC E3.9.83.
This episode and the call of the Abbé Pierre in 1954 was represented in articles, books and films.
- 53 A. Wogenscky, letter to Tancreze (Ets Missenard-Quint), 21 July 1955, FLC E3.9.548.
- 54 A. Wogenscky, FLC E3.9.548.
- 55 A. Wogenscky, "Chauffage de notre atelier", 6 September 1955, FLC E3.9.663.
- 56 Le Corbusier and R. Andreini, letter to Dusseris (Ets Missenard-Quint), 11 December 1957, FLC E3.11.208.
- 57 Le Corbusier and F. Gardien, letter to Dusseris (Ets Missenard-Quint), 21 January 1955, FLC H2.6.317.
- 58 R. Dusseris (Ets Missenard-Quint), letter to Le Corbusier, 15 July 1958, FLC H2.6.333.
- 59 Le Corbusier, letter to Ets Missenard-Quint (Dusseris), 21 July 1958, FLC H2.6.334.
- 60 *Les chroniques météo de l'année 1958*, Météo Paris, consulted on 17 August 2014, <http://www.meteo-paris.com/chronique/annee/1958>
- 61 André Missenard, letter to André Wogenscky, 13 December 1954, FLC A3.13.70.
- 62 *Les chroniques météo de l'année 1954*, Météo Paris, consulted on 25 August 2014, <http://www.meteo-paris.com/chronique/annee/1954>
- 63 André Wogenscky, letter to André Missenard, 17 December 1954, FLC A3.13.71.
- 64 Ets Missenard-Quint, "Quelques références", n.d., FLC Q1.15.225.
- 65 Ets Missenard-Quint, "Chauffage par rayonnement. Sol-plafond", n.d., FLC Q1.15.217.
- 66 Ets Missenard-Quint, "Nouvelles techniques des Climats artificielles", n.d., FLC Q1.15.259.

4.2 PROFESSIONAL COLLABORATIONS

The archival research at the FLC reveals six collaborations between the *Atelier 35S* and the *Ets Missenard-Quint* from 1951 to 1965. Additionally, the environmental control issues were highlighted in three other projects, where Missenard's lessons were recalled to some extent. Their professional collaboration has been documented in five complete works (*Maisons Jaoul*, *Unité d'Habitation Rezé-les-Nantes*, *Maison du Brésil*, *Unité d'habitation Briey-en-forêt* and *Unité d'habitation Firminy-Vert*), a project consultancy (*Grille Climatique*) and indirectly in three projects (*Couvent de la Tourette*, *Musée national de l'art occidental Tokyo* and the *Centre de calculs électroniques Olivetti*).

The previous study of their personal correspondance reflects that neither architect nor engineer were equally involved in the projects of their respective companies. They created, however, such a strong theoretical and practical framework for their collaborators that their thought ruled over all their works. Thus, the professional association of their offices, where Le Corbusier was always engaged, is a testimony of the practical exchange of their theoretical backgrounds.

In this chapter we will address the reconstruction of the story of the works paying attention to the notions previously developed compared with the technical and architectural strategies that were used to materialize them. As a result, the project stories have only dealt with these main topics, because most of them have been widely studied from other viewpoints.

MAISONS JAUL, NEUILLY-SUR-SEINE, 1951-1955

The first evidence of this collaboration is dated July 1952, more than one year after Le Corbusier had convinced André Jaoul to be in charge of the project of his son's house. As Maniaque reports (2005, 36), the architect assured that he could build two houses with the same budget that the previous architect, who was the Britishman Clive Entwistle (1916-1976), invested in building only one⁶⁸. Besides, he thrilled the businessman by recalling the idea of a construction in brick and vaults, "*Et vous aurez des voûtes !*", which apparently was proof of architectural quality in this context. Several documents preserved at the FLC's archive show the enthusiasm of Le Corbusier for building with vaults during the late-1940s and early-1950s, such as the sketches of the *Carnet E21* (1951)⁶⁹ or the project for the *Maisons Roq et Rob in Cap-Martin* (1949)⁷⁰.

On 11 July 1952⁷¹, Dusseris sent a letter to the *Atelier 35S* with the description of the heating system for two pavilions in Neuilly-sur-Seine. As they used to do, the *Ets Missenard-Quint* proposed a radiant heating system by using floor and ceiling surfaces to create a very comfortable installation. The water would be heated in a common boiler fed with fuel and it would be regulated to provide hot water at 28°C for an outside temperature of 7°C.

Besides, Dusseris did the cost estimation for the ceiling heating system applying *Crittall's* patent. At the end of the text he sketched out a second option for saving money by using Missenard's patent for floor heating systems. In this way, he argued, all the superposed spaces would be heated by the single use of the intermediate slab. In the case where this option was chosen, however, he suggested to discuss some modifications to the slab layer's composition.

A few days later, on 15th July⁷², Missenard sent a letter to Le Corbusier commenting that Dusseris (*Ets Missenard-Quint*) and Le Marchand (*Atelier 35S*) had notified him about the *Atelier 35S* consultation for the heating system of the two houses. Following Dusseris' letter, Missenard argued in favour of the floor heating system due to the cost saving in comparison with *Crittall's* system. On 28th July, Dusseris⁷³ sent a budget that fully detailed the cost of both choices without showing preference for one or another. He just described the thermal conditions of the floor's water as 28°C, as a reference to the comfort level.

Maniaque (2005, 65) reports that the architects sent a copy of the plans to all the contractors based on the drawings dated 17th April 1952, which were submitted for the second attempt of obtaining the construction licence. These drawings represented an almost definitive version of the space arrangement and the constructive characteristics of walls and slabs. The heating engineers collaboration likely started with this reference.

The construction licence was delivered on 23rd October 1952 with the last version of the plans dated 11th September 1952⁷⁴. According to the previous project, they only changed entrances and windows in the North-West façades. Last of all, a third series of plans was drawn on 8th January 1953⁷⁵, which finally represented the project that was built.

On 15th April 1953⁷⁶, Wogensky informed the contractors by mail that Jaoul was going to begin the construction. On 5th May⁷⁷, Wogensky and Gardien sent a letter to Dusseris in order to announce the beginning of the works and to request them officially for their collaboration in the project and construction of the heating system and the fireplace of both houses. The architect stated that the comfort level desired for the

project was “*confort moyen*”, expression that was deliberately related to the cost of the system. Actually, as Maniaque (2005, 65) reports, the works were quite conditioned by budgetary restrictions.

A few weeks later, on 29th May⁷⁸, the engineers sent a list of changes in pipes, heating coils and valves to the *Atelier 35S* aimed to save 350000 Frs. Besides, they reported that they were trying to agree with *Allard* (construction company) on the vaulted slabs solution to integrate the floor heating system.

During Jaoul’s familiar holidays in Saint-Jean de Luz (July and August), the engineering firm required Jaoul to sign an official agreement of their proposal for the heating system. Right after, on 31st July 1953⁷⁹, he addressed a handwritten letter to the *Atelier 35S* expressing his agreement with the engineers’ project. Ironically, the architects waited to forward the copy to the engineers on 1st October⁸⁰. Then, Wogensky confirmed the commission of the heating system to *Ets Missenard-Quint* and repeated the necessity of adapting their proposal to a level of “*confort moyen*”.

On 30th October⁸¹, Le Corbusier and Michel sent a mail to the engineers underlining two doubts about the installation’s execution: the concrete procedure for filling the haunches of the first floor’s vaults and the eventual waterproof problems of the heating slab. They instigated the engineers to find an agreement for the construction procedure with *Allard*. Besides, the architects alluded to the flooring material, because they were waiting for a solution for house B.

In November 1953 a mail exchange took place between *Ets Missenard-Quint*, *Allard* and *Atelier 35S* regarding the aforementioned topics, including plans and technical descriptions of the adopted solutions. It finished when the engineers sent the plans to Le Corbusier’s office on 19th January 1954⁸².

The project removed the ceiling heating system of the first floor’s vaults and increased the density of the heated-slab coil. They suggested that the ground floor would benefit from heat recovering from the first floor installation. As a result, the ground floor design took into account its own heated floor as well as the effect of the ceiling radiation on the first level.

On 5th March 1954⁸³, Le Corbusier and Michel contested the engineers’ proposal. They asked for a fully detailed explanation of the system because they doubted about the resultant comfort by the use of a combined system: “*Je mets en doute le confort que peut procurer une installation de chauffage par le plafond plutôt que par le sol pour la rez-de-chaussée de la maison B*”⁸⁴. The architect consequently refused the installation until further notice.

Only five days later, on 10th March 1954⁸⁵, Dusseris answered Le Corbusier explaining in detail the three main points. Firstly, he clarified that the concentration of heating pipes at the first floor would significantly reduce the energy consumption and he added a heat-transfer study to provide evidence of it. Secondly, he claimed that they would guarantee the indoor temperatures and their constant regulation by an automatic ventilation system as previously established. Lastly, he explained that there were almost imperceptible differences in terms of comfort between the floor and ceiling heating system, due to the radiant heat-transfer logic. He even argued in favour of the heat source on the ceiling briefly recalling satisfactory experiences in Switzerland and Germany, with the only negative point being the cost.

On 6th May⁸⁶, the engineers sent a letter to the architects in response to a requirement of Jaoul in order to be guaranteed that the metallic coils would not have corrosion problems. Even if they gave the guarantee, it was matter of a second letter on 18th May⁸⁷, which finally found a solution to all the doubts.

On 21st May 1954⁸⁸, Michel asked urgently for the plans of the radiant floor pipes of the first floor of the house B. The answer was likely provided in July 1954, given that after the plans of November 1953, the following plans preserved at the FLC's archive were dated from 8th June to 9th July 1954. These drawings represented the heating panels to be introduced in the slabs, also paying attention to the gutter for installations crossing at the ground floor. Exceptionally, a plan has been found that is dated 9th September 1954⁸⁹ and that modifies the plan of the second floor coils.

Once the concrete was filled over the vaults, the heating coils were disposed over the concrete. Afterwards they were covered with cement, creating a slab of 4 cm in depth on average. Finally, the flooring in cement tiles or parquet was installed directly over the slab. The architects were not completely sure of how the heated-slab would work in the future. In fact, they feared that the thermal effects might cause cracks in both covering and bricks⁹⁰. Thus, even if the vaults of the ground floor were finished in exposed brick, the vaults of the first floor were finally plastered.

During the rest of the construction period (end of 1955), there are no evidences of main troubles with the heating systems or with the company *Ets Missenard-Quint*. The written documents of this period refer to the boiler installation, the re-drawing of plans according to the work conditions and the payments.

One year later, on 6th July 1955⁹¹, Wogenscky wrote to Tancreze asking for their best in order to have the hot water installation working for the following Monday because the owners wanted to move in. At the end of the month, Michel asked for the finishing of the insulation of the hot water ducts. This happened in October⁹², when Dusseris answered that they were waiting for the tests of the heating system before insulating the last parts.

After several years experience in the house, the daughter of Jaoul explained in an interview how she grew up in this modern house (Barré 1979). She recalled common criticisms of Modern Architecture, such as privacy problems, lack of cosiness in terms of walls' textures and furniture, as well as the industrial exterior appearance in comparison with her friends' houses. She also reported daylight troubles in the rooms, but she never criticized the fireplace, the heating systems or the house's ventilation.

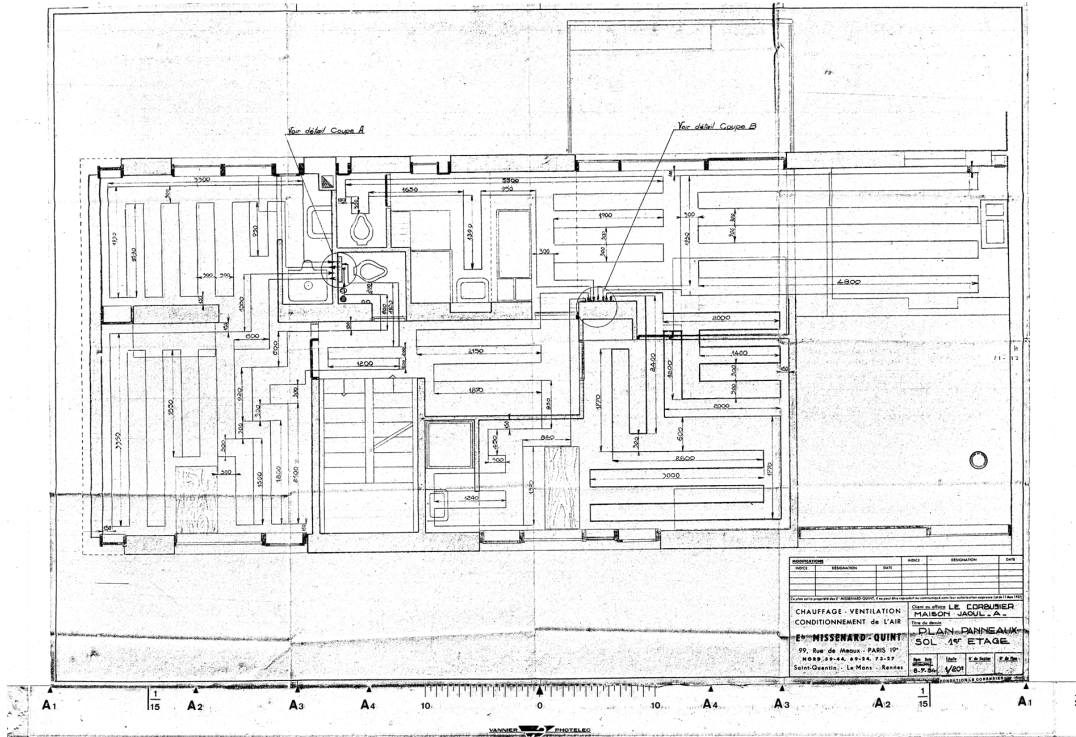


Figure 14. Heated-slab coils plan

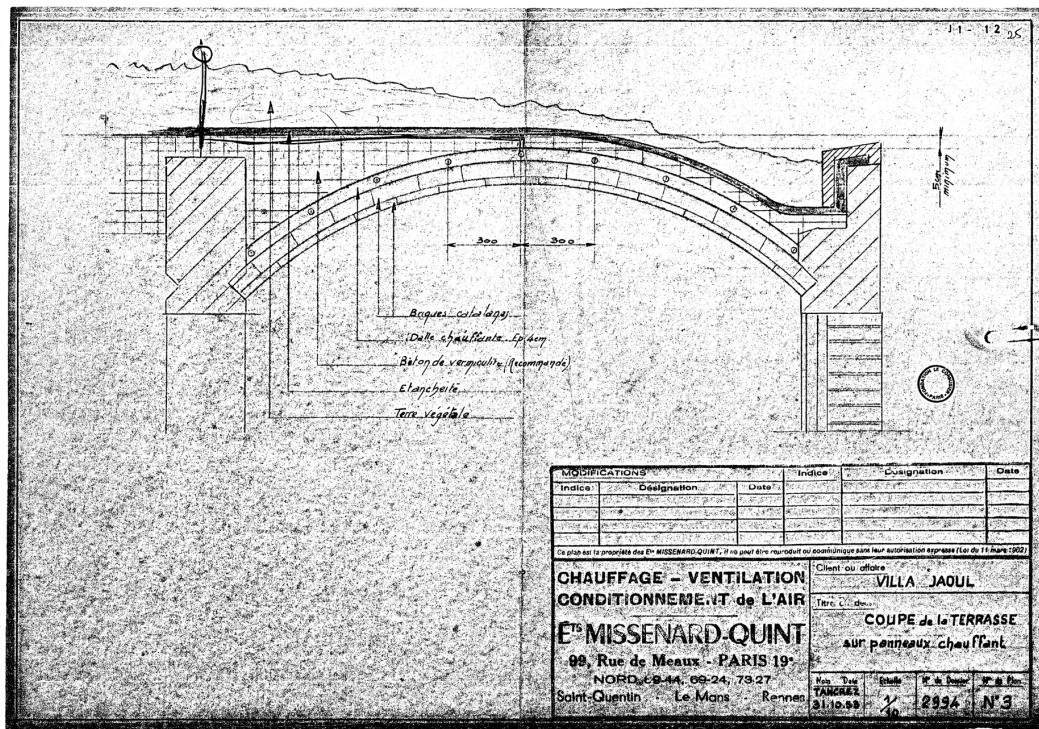


Figure 15. Heated-slab embedded in the vaults

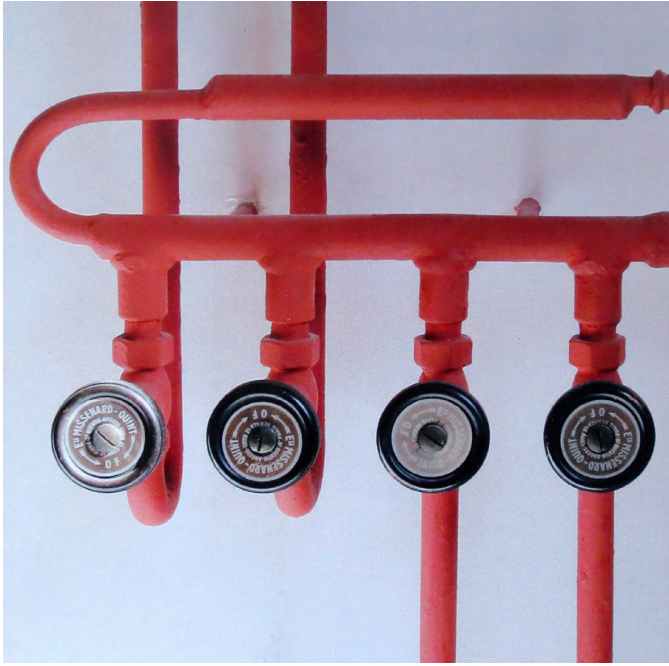


Figure 16. Heating system detail by Ets Missehard Quint (Maniaque, 2005)



Figure 17. Heating system ducts

NOTES:

- 68 FLC 10077, Ground floor plan, 8 Juin 1951.
- 69 Cf. Carnet E21, July 1951, archive FLC.
- 70 Other projects and works recalled the use of the catalan vaults that Le Corbusier learnt with Josep Lluís Sert. For instance: Atelier Rue Nungesser-et-Coli (Paris, 1931-34), Weekend house (La Celle-Saint-Cloud, 1935), Domaine agricole (Peyrissac, 1940) or Houses Roq et Rob (Cap-Martin, 1949).
- 71 P. Dusseris (Ets Missenard-Quint), "Chauffage de deux pavillons", 11 July 1952, FLC J1-14-131.
- 72 A. Missenard, letter to Le Corbusier, 15 July 1952, FLC E2-16-18.
- 73 P. Dusseris (Ets Missenard-Quint), "Chauffage des 2 Villas", 28 July 1952, FLC J1.14.134.
- 74 FLC 10082.
- 75 Plans from FLC 4534 to 4560.
- 76 A. Wogenscky, letter to Ets Missenard-Quint, Paul Deux and MODEP, 15 April 1953, FLC E3.3.269.
- 77 A. Wogenscky and F. Gardien, letter to P. Dusseris (Ets Missenard-Quint), 5 May 1953, FLC E3.3.322.
- 78 R. Dusseris (Ets Missenard-Quint), "Maisons Jaoul à Neuilly", 29 May 1953, FLC J1.14.138.
- 79 A. Jaoul, letter to the Atelier Le Corbusier, 31 July 1953, FLC J1.14.139.
- 80 A. Wogenscky and F. Gardien, "Maisons Jaoul", 1 October 1953, FLC E3.4.137.
- 81 Le Corbusier and J. Michel, "Maisons Jaoul", 30 October 1953, FLC E3.4.294.
- 82 J. Michel (Atelier 35S), "Maisons Jaoul à Neuilly", 19 January 1954, FLC J1.14.151.
- 83 Le Corbusier, "Immeubles Jaoul à Neuilly", 5 March 1954, FLC J1.14.159.
- 84 Le Corbusier, FLC J1.14.159.
- 85 P. Dusseris (Ets Missenard-Quint), "Mt/Sc Villa M. Jaoul", FLC J1.16.512.
- 86 P. Dusseris (Ets Missenard-Quint), "Maisons Jaoul à Neuilly", 6 May 1954, FLC J1.14.166.
- 87 A. Wogenscky, "Maisons Jaoul à Neuilly", 18 May 1954, FLC J1.16.192.
- 88 J. Michel, "Maisons Jaoul à Neuilly", 21 May 1954, FLC J1.14.165.
- 89 Ets Missenard-Quint, "Maison Jaoul A. Plan Paneaux. Sol 2eme étage", 9 September 1954, FLC J1.12.6.
- 90 Le Corbusier and J. Michel, letter to Tancreze (Ets Missenard-Quint), 12 November 1953, FLC E3.4.338.
- 91 A. Wogenscky and F. Gardien, "Maisons Jaoul à Neuilly", 6 July 1955, FLC E3.9.459.
- 92 P. Dusseris (Ets Missenard-Quint), "OP/PR - Maisons Jaoul", 6 October 1955, FLC J1.16.517.

THE GRILLE CLIMATIQUE, 1951

Once Le Corbusier came back from his journey to India, he wrote a letter to Missenard on 2nd December 1951⁹³ asking for advice for the project of Chandigarh. As he wrote, the troubles and challenges issued from the Indian context, but also from the construction in any climate, needed collaborative work among biologists, physicists and architects. He pointed especially to the development of new rules for architectural environments taking into account the hygienic matters; nevertheless they should state a different approach from European ones, where he considered the regulations too conformist. As Le Corbusier noted, *“impliquent ses décisions à prendre concernant les lois de l'hygiène (de tout autre nature que nos règlementations conformistes et fruits de tous les compromis)”*.

A second letter of Le Corbusier dated 6th December⁹⁴, which seemed to follow an intermediate meeting on the same day, detailed the collaboration procedure. The *Atelier 35S* would send to Missenard a questionnaire with their doubts. It should be answered with an affirmative or negative response, or even with a modification sketch. According to the results of this analysis, Le Corbusier continued, they would figure out how to follow the collaboration for the case of main buildings, like the *Secretariat* or the *Assembly*. In the meanwhile, Le Corbusier suggested requesting the Punjab authorization to make a payment of 50000 francs for Missenard's professional fees.

Missenard answered with a mail on 12th December⁹⁵ showing his enthusiasm in this new project. He also asked for the questionnaire and proposed to arrange a meeting to explain his answers to them in detail. Lastly, he argued in favour of linking efforts in order to obtain the best results possible according to the *Ets Missenard-Quint's* systems and the climatic conditions of Chandigarh.

On 16th December, Xenakis defined the main lines of a *“Programme d'Etudes des Conditions Climatiques Optima et des Moyens Architecturaux de correction”*⁹⁶. As Siret (2005c) states, the programme was put together in a precise manner that seemed to be influenced by the theories of Missenard. As a matter of fact, Xenakis defined what he called *“l'ambiance climatique”* depending on four variables: temperature, relative humidity, air velocity and wall temperature. These were the factors that Missenard had stated since the late-1930s as the most influential for human thermal comfort.

As Siret reports, the architects proposed to *“définir les variations optima et théoriques de l'ambiance pour conserver ou accroître le meilleur rendement VITAL”* by considering diurnal and annual variations. For them, the objective consisted in *“trouver d'après les données climatiques et les résultats théoriques préétablis les procédés architecturaux de correction. Ceci au moyen d'une grille (voir le tirage)”*.

The copy was probably the presentation panel dated 21st December⁹⁷ and entitled *“Esquisse générale de la grille pour le conditionnement climatique du Secrétariat”*. The drawing done by Samper took into consideration six physical factors instead of four: sun, light, air temperature, prevailing winds, rainfall and relative humidity (Gargiani and Rosellini 2011, 219). The chart was divided into three columns, which corresponded to the three stages in the method: recording of climate data for the site (*données climatiques*), the optimal conditions to be attained (*conditions optimes*) and the architectural processes to be adopted (*procédés architecturaux*). The facts of these charts were represented through general diagram of each one of the columns, which shows their tentative character.

Once the drawing was done, Le Corbusier wrote to Jane Drew to report about the invention. In his own words: *"Nous avons eu la deuxième séance avec M. Missenard, nous avons créé une 'grille d'hygiène climatique' qui nous permet de voir clair à travers notre problème. Nous avançons très vite et nous arrivons à des propositions utiles"*⁹⁸

On 29th December⁹⁹, Xenakis sent to Missenard the *Grille Climatique* with the climatic facts provided by the Executive Engineer of the Capital Project Division in Chandigarh. They tried to write down in the grid the most details possible to facilitate Missenard's answer with the climatic corrections needed and to foster other advice or proposals. They also attached some documents related with the project *Type d'Habitation Populaire*, which apparently appeared afterwards in the *Maison des Péons*.

On 16th January 1952¹⁰⁰, Missenard met with Le Corbusier, Maisonnier, Samper and Xenakis with the aim of studying the environmental corrections proposed by the *Grille Climatique*. As a result, the document entitled *"Correction désirables dans les locaux (A. Missenard)"* collected the comments of the engineer. This chart was divided in a column for each month and four rows, which represented the environmental factors of air temperature, humidity, air velocity and solar radiation. The squares explained the desirable environmental corrections in order to achieve the ideal indoor conditions according to the collected data for each month.

The notes of the engineer adopted physical expressions to refer to each one of the environmental characteristics of the space. For air temperature and relative humidity, which were detailed in Celsius degrees and percentages, the corrections were expressed in terms of degrees to cool and the time lapse to do it. When no correction was needed, he wrote down *"satisfaisant"*. Air velocity comments were explained in terms of desirability according velocity ranges of 3.0 m/s and 1.5 m/s. Lastly, he added qualitative notes for solar radiation, only pointing if they were or not advisable according to the spaces, although most of his comments were just oriented to *"à éviter"*, *"à proscrire"* or *"à proscrire absolument"*.

The definitive chart was drawn in a document dated 31st January 1952 and signed *"Atelier LE CORBUSIER"*¹⁰¹. The chart was defined as *"un moyen matériel de visualisation permettant d'énumérer, de coordonner et d'analyser les données climatiques d'un lieu défini (par sa latitude) afin d'orienter la recherche architecturale vers des solutions accordées à la biologie humaine. Il s'agit de régulariser et de rectifier utilement les débordements de climats excessifs et de réaliser par des dispositifs architecturaux les conditions capables d'assurer le bien-être et le confort"*. Once again, the expressions and notions adopted in the text seem to link it with Missenard's artificial climates theory.

The first column of the chart concerned the *"Conditions des ambiances"*. The six factors of Xenakis' diagram on 21st December 1951 were replaced by the four factors stated by Missenard, which were previously summarized by Xenakis on 16th December 1951.

The second column was entitled *"Corrections en vue du confort et du bien-être"*, a new title that removed clear Missenard influences in the terms of *"conditions optimale"* or *"meilleur rendement vital"*. As they proposed, in the squares of this column *"le physico-biologiste inscrira les corrections ou rectifications jugées indispensables. Ainsi, la lecture du second panneau de la Grille constitue-t-elle le programme même motivant l'intervention de l'architecte"*.

Lastly, the third column carried the title "*Architectural solutions*" and was drawn up according to a precise protocol. As Siret explains, it did not aim to represent the schematic solutions in graphical terms on the chart itself but rather at signalling by the presence of a stamp (the letter D for drawing) the existence of a solution, referenced in the body of the stamp and accompanied by an explanatory diagram.

The first test of this new design procedure was completed on the project for the *Maisons des Péons* in Chandigarh. The details and solutions proposed, as well as the subsequent meetings and discussions with Jane Drew and Varma, are duly explained by Siret in his article "*Grille Climatique - 1951*" (Siret 2005c). On 14th May, Drew informed Le Corbusier of an exhibition project about Chandigarh in New York and asked him if it would be possible to include in it, along with the CIAM town planning charter, the climate chart¹⁰². Le Corbusier approved in his reply of 4th June 1952.

On 20th June, in answer to a request made by Doshi on 20th May, the Meteorological Bureau of India sent, to rue de Sèvres, the weather data recorded month by month for the cities of Ahmedabad and Ambala, the latter being the meteorological station closest to Chandigarh.

All this effervescent creative procedure was not reported to Missenard, as reflected in his mail to Le Corbusier on 15th July¹⁰³. With the excuse of introducing a discussion about the *Maisons Jaoul*, he showed himself interested in the progression of the Indian projects and the results of the "*dispositions que nous avons étudiées ensemble*"¹⁰⁴. This mail was not answered until 8th October, when Le Corbusier only expressed his apologies for not giving news about the project and he attached a payment check against his professional fees. On 16th October¹⁰⁵, Missenard answered gratefully for the check but he also informed of his availability for any kind of complementary help or information without involving a new payment.

On 22nd July, Le Corbusier wrote to Drew and referred briefly to the climate chart. Over a year later, G. Samper sent to J.L. Malhotra at Chandigarh "*une copie de la grille climatique exécuté à l'atelier en janvier 1952*"¹⁰⁶. He pointed out that it was established upon weather reports from Ambala "*qui sont quelque peu différentes de celles de Chandigarh (...). Cette grille doit donc être considérée comme un exemple à titre indicative*".

According to Siret, the chart disappeared from correspondence and plans, even if many drawings hold the same thought that generated the chart. The climatic section *Secretariat* project (FLC2827), for instance, shows the effects of sun, light, rain and air movement. In a similar way, the drawing FLC4639 shows a study of natural and artificial ventilation for the *High Court*. These questions of climate adaption were also studied for the *Villa Sarabhai* (FLC6676). Other indications that pointed to climatic awareness were the inclusion of wind roses in plans, with the highest solar height angle in winter and summer or the direction of prevalent winds for each season (e.g., FLC29150 and FLC4891) (Requena Ruiz 2012a).

The last reference to the *Grille climatique* was in January 1959, when Le Corbusier asked Maisonnier and Xenakis "*d'envoyer de toute urgence à Pierre Jeanneret une épure type de tracés de brise-soleil et une Grille Climatique*"¹⁰⁷. They were sent on 12th February 1959, accompanied by a letter in which Le Corbusier himself put an end to the history of the climate chart: "*Mon cher Pierre, je t'envoie (...) la Grille Climatique ayant servi à motiver les données architecturales de l'étude des maisons de péons. Rien de tout ceci n'a*

été réalisé, mais la méthode de travail qu'autorisait la Grille Climatique était intéressante"¹⁰⁸.

Even if the relevance of the invention was evident, Le Corbusier did not recognize it in his posthumous note entitled *12 petites inventions* (Petit 1970). He focused his interest on materialized proposals such as the *brise-soleil*, the *aérateur* and the *pan de verre ondulatoire*.

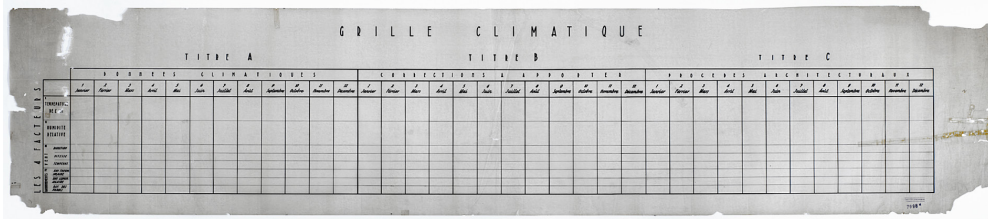


Figure 18. Grille climatique (FLC 07998)

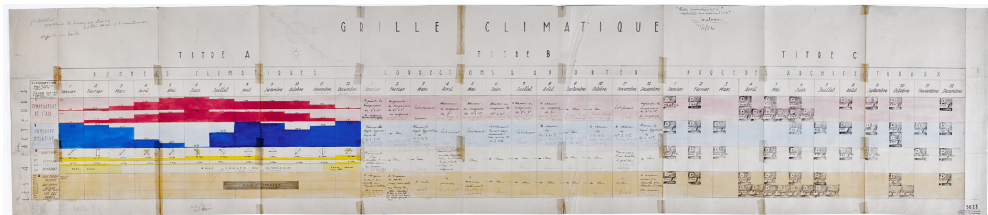


Figure 19. Grille climatique (FLC 05623)

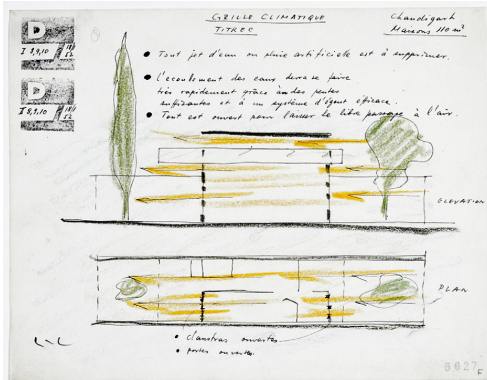


Figure 20. Ventilation sketch (FLC 5627f)

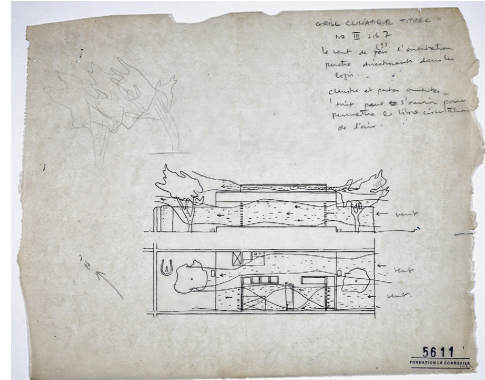


Figure 21. Ventilation drawings (FLC5611)

LAUSANNE (1903)

Corrections désirables dans les locaux (A. Miesner)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|--|--|--|---------------------------------------|---|---|---|---------------------------------------|-----------|---------------------|-----------------------|---|
| Janvier | Février | Mars | Avril | Mai | Juin | Juillet | Août | Septembre | Octobre | Novembre | Décembre |
| Augmenter la température moyenne de 2 à 3° | Augmenter la température moyenne de 2 à 3° | Satisfaisant | Abaisser la température moyenne de 7° | Abaisser la température moyenne de 10 à 12° | Abaisser la température moyenne de 12 à 14° | Abaisser la température moyenne de 7 à 5° | Abaisser la température moyenne de 7° | Idem | Idem | Satisfaisant | Augmenter la température moyenne de 2 à 3° |
| Humidité hygro-métrique 20 à 22% | Idem | Augmenter la humidité hygro-métrique de 15 à 20% | Satisfaisant | Satisfaisant | Satisfaisant | Satisfaisant | Abaisser de 20 à 25% | Idem | Abaisser de 5 à 10% | Abaisser de 10 à 15% | Abaisser la humidité hygro-métrique de 20 à 25% |
| Il y a trop de soleil | Idem | Idem | Il y a trop de soleil | Il y a trop de soleil | Il y a trop de soleil | Il y a trop de soleil | Il y a trop de soleil | Idem | Idem | Il y a trop de soleil | Il y a trop de soleil |
| On a besoin d'air pur | On a besoin d'air pur | Idem | Idem | Idem | Idem | Idem | Idem | Idem | Idem | Idem | On a besoin d'air pur |

Figure 22. Chart with Miesner's notes and advises (FLC P2-1-27)

NOTES:

- 93 Le Corbusier, letter to André Missenard, 3 December 1951, FLC E2.16.14.
- 94 Le Corbusier, letter to André Missenard, 6 December 1951, FLC E2.16.15.
- 95 A. Missenard, letter to Le Corbusier, 12 December 1951, FLC E2.16.16.
- 96 I. Xenakis, "Programme d'études des Conditions Climatiques Optima et des Moyens Architecturaux de correction", 16 December 1951, FLC P2.1.1.
- 97 Atelier Le Corbusier, "Esquisse général de la Grille pour le conditionnement climatique du Secrétariat," 21 December 1952, FLC 2642.
- 98 Le Corbusier, letter to J. Drew, 21 December 1951, FLC P2.1.9.
- 99 A. Missenard, letter to Xenakis, 29 December 1951, FLC E2.16.17.
- 100 A. Missenard, "Réunion Grille Climatique", 16 January 1952, FLC P2.1.27.
- 101 Atelier Le Corbusier, 31 January 1952, FLC P2.1.3.
- 102 J. Drew, letter to Le Corbusier, 14 May 1952, FLC P2.1.29.
- 103 André Missenard, letter to Le Corbusier, 15 July 1952, FLC E2.16.18.
- 104 Missenard, FLC E2.16.18.
- 105 André Missenard, letter to Le Corbusier, 16 October 1952, FLC E2.16.20.
- 106 FLC P2.11.21.
- 107 Le Corbusier, letter to Maisonnier and I. Xenakis, January 1959, FLC P2.1.32.
- 108 Le Corbusier, letter to P. Jeanneret, 12 February 1959, FLC P1.13.34.

UNITÉ D'HABITATION, REZÉ, 1949-56

Designed and built from 1949 to 1955, the *Unité d'Habitation* in Rezé-les-Nantes was the second realisation of this housing-prototype after Marseille's building. The commission was received from the *Société Coopérative d'Habitations à Loyers Modérés* called *La Maison Familiale*. It aimed constructing a housing building for the employees of the harbour of Nantes, but the location was not assigned yet.

This project, like the previous in Marseille, was based on the encouragement of the Ministry of Reconstruction for experimental projects in social housing. This framework was provided by the law of 25th July 1949 "*Constructions de caractère expérimental*", which mainly allowed architectural innovations in terms of dimensions, forms and functionality.

Rezé's project was the first *Unité* built in the French legal framework of the *Habitation à Loyer Modéré* (HLM). Like Marza and Tinacci (2005) state, this point complicated all the negotiation process during the early design phase. It also led to changes of the original proposals because of the budget restrictions imposed by the regulation.

The new building only preserved the general profile and the apartments scheme of Marseille, but the public spaces and housing typologies were modified to greater or lesser extent. Besides, a whole range of construction systems were changed in order to adapt the original proposal to the actual conditions imposed in Rezé. Mainly, they affected both reinforced concrete and metallic structures, the acoustic insulation, the heating and ventilation systems, the prefabrication procedures, the services networks, the flooring materials and the roof.

The construction changes also involved the replacement of several of the external collaborators. As a matter of fact, the radical transformation of the structure to achieve the reduction of scaffolding and wooden formwork, together with the ending of Le Corbusier's collaboration with Bodiansky, led to the integration of Laffaille and Eugène Freyssinet (Gargiani and Rosellini 2011, 151). The well-known French engineer worked on the pre-stressed concrete elements. This type of change was also operated for the heating and ventilation system.

The early proposal was based on the same 'air-conditioning' scheme implemented in Marseille. In the first phase of the project, the plan drawn by Gardien on 16th February 1951¹⁰⁹ proved the primitive intention. In contrast, a second scheme dated 1951¹¹⁰, reveals a completely different scheme with a boiler and regulation valves for circuits in each one of the East, West and South façades.

In July 1952, *La Maison Familiale* opened the application procedure for the companies that wanted to take part in the construction. They required applications files for the construction of the entire building, what fostered a grouping of specialised companies. On 21st October (Monnier 2005), the jury opened the sealed bids accompanied by the agents of the *Atelier 35S* Wogenscky and Ducret. The results were not satisfying for the jury members because the budgets were about two and three times more expensive than the maximum reference established at 800 million Francs. Besides, as the charts FLC 02537 and FLC 02538 evidence, the companies' application files did not include all the chapters required, so they were not acceptable. Regarding thermal comfort, the *EMGEN* company suggested installing a "*chauffage air pulsé*", to remove the *brise-soleil* but preserving the frame of the loggia and to use single glazed windows. The *Pérignon* company preserved the *brise-soleil* and proposed to install a warm air central heating

system in association with *Carrier*. The chart FLC 02538 shows the appraisals of the jury about their proposal: “Donnée 18° par 0°. Renouvellement 1 à 1,5 à l’heure. Plinthe chauffante et évacuation d’air vicié. Intéressant : gaines verticales prévues”. Even keeping the original approach of warm air central heating, these notes reveal that the jury was open-minded to different heating system proposals.

In fact, the local companies that applied were suspicious of the experimental character of the building, idea that was also fed by the negative critics of the *Unité d’habitation* in Marseille. Wogenscky criticized the companies strategy: “*Les exigences du dossier avaient été volontairement d’ailleurs, très nombreuses, dépassant de loin les caractéristiques normales des projets H.L.M. : appartements plus grands, pilotis et terrain artificiel, loggias, installation de chauffage et d’air pulse chaud et froid [...] La concurrence n’a pas assez joué sur certains lots et même pas de tout sur certains autres (ventilation, fournitures de sanitaires et canalisations, menuiserie)*”¹¹¹.

From December 1952 to January 1953 several jury meetings took place in Nantes for choosing the construction company for the structure and the shell. Le Corbusier’s comments during the jury sessions centred on the necessity for contracting experienced companies in the innovative techniques that this work involved: “*cette réalisation va nécessiter des méthodes extrêmement modernes de construction qui demandent des techniciens éprouvés*” (Monnier 2005). Finally, they recognized the experience of the Parisian *Compagnie d’Entreprises Electriques, Mécaniques et de Travaux Publics* (CEEMTP) to the detriment of the local companies. Nonetheless, some chapters were open to applications independently, among them, the chapter of heating and ventilation systems received offers from three companies: *Ets Neu* (Lille), *Carrier Corporation* (Paris) and *Ets Missenard-Quint* (Paris).

In this regard, a mail dated 9th January 1953¹¹² Wogenscky confirmed the reception of the proposal of *Ets Missenard-Quint* that was out of date, so he proposed waiting to forward it directly to the *Maison Familiale* at a later date. After that, Wogenscky sent a letter on 11th February 1953¹¹³ to all the applicants, including Missenard’s firm, in order to request the three companies a balance sheet of the running costs in specific conditions of indoor and outdoor temperatures. Thus, the economic constraints of this project started to be evidenced in the thermal comfort services.

On 5th March¹¹⁴, Wogenscky informed all the three companies of the jury’s choice in favour of the “*chauffage par le sol, système Missenard-Quint*”¹¹⁵. Even so, Missenard’s proposal seemed to be in mind for the jury several days before. On 27th February 1953¹¹⁶, Wogenscky asked *Ets Missenard-Quint* for more details of the system as well as an explanation of the changes involved by their heated-slab proposal. At the same time, Wogenscky argued in favour of the company MODEP in front of the property, supporting their experience in flooring for heated-slabs: “*Seule la société MODEP a jusqu’ici réalisé des chapes de ce type sur sol chauffant*” (Monnier 2005).

Once *Ets Missenard-Quint* was chosen, Wogenscky sent a letter on 6th March¹¹⁷ to inform the other contractors of the changes involved in the project by the new heating system: coils, pipes and insulation bands for the heating slab; plastic separation between the walls and the heating layer; different flooring at the lift zone; and changing dimensions of the entire building according to the walls.

Wogenscky noted the relevance of these changes in the meeting with all the companies at the CEEMTP offices on 10th March¹¹⁸. The architect focused on

organisational issues, paying attention to the new heated-slab. He also specified that the flooring would be according to *Dalami's* patent. A system of squared slabs 30x30 cm made of vinyl with asbestos fibres isolated inside a plastic mass of 1 cm in thickness.

The heating system was based on the heated-slab patent *Système Missenard*. The suggested scheme introduced the hot water coils in the concrete slabs of the apartments' floor. Each one of the coils would be connected to a specific circuit according to its characteristics of exposure and orientation. Five circuits were designed to specifically serve the kindergarten, the South gable end, the East façade spaces, the West façade spaces and the first floor (Monnier 2005, 76).

Even if no other evidence of the system design has been found, this scheme was proposed for the following projects of their collaboration. Different orientations were heated in different temperatures according to the sunlight exposure; therefore, the water temperature was not the same in each one of the circuits, which kept the different zones independent according to a gains and losses study. The first floor and last floor were also differently heated according to their particular exposure conditions. Furthermore, the boilers activation was regulated by using an innovative temperature control system, which was conceived by the engineers in 1953 (Gargiani and Rosellini 2011, 157), which changed the water temperature according to the outside. This regulation system was also detailed for the subsequent projects for the *Unité d'habitation*.

The floor turned into a central issue in the construction of this second *Unité d'habitation*. As previously happened in the 1920s with the *Mur neutralisant*, the floor became a complex organ conceived as a main surface that integrated the heating system of the apartments and provided both thermal and acoustic insulation. Functions that were added to the structural one.

The sanitary ventilation was limited to a minimal network whose entrances were through the *aérateurs* included in the *pan-de-verres* and the air exits were integrated in bathrooms and kitchens. The latter were connected through ducts to a services passage under the roof that was ventilated by fans connected to the chimneys.

Apart from the project elaboration, the engineers developed a program of performance tests in a full prototype of the heated-slab. On 15 April 1953¹¹⁹, the director of the *Centre Scientifique et Technique du Bâtiment* (CSTB) informed the *Atelier 35S* about the agreement with all the companies involved in the prototype for the tests by mail, namely: *Saint-Gobain* (glass wool insulation), *Ets Missenard-Quint* (hot water pipes) and *MODEP-Dalami* (flooring material).

On 21st July¹²⁰, the first cycle of tests was conducted according to the regulations of the CSTB at the laboratories of Champs-sur-Marne. At the end of this process, Dusseris informed the *Atelier 35S* by mail that the engineer of *Bureau Veritas* had found fissures in the concrete slab when it was heated more than 80°C. In addition, he informed them that the *Dalami* preserved its physical integrity even with some peaks of 100°C.

On 7th September¹²¹, Dusseris wrote to the contractors to explain the development of a new program of tests. On 28th September¹²², the engineers sent another mail with a plan attached that detailed the test slab. Then, on 19th October¹²³, Dusseris informed to the other contractors about the procedure and the results of the tests of both heating system and flooring material, which were positive for all the tests. At the end of the

year¹²⁴, Wogensky invited *Bureau Veritas*' representatives to visit the last test session to be done at *Ets Missenard-Quint*'s headquarters in Paris.

In the meanwhile, the engineers worked in the composition of the project for the *Unité d'habitation*, which was presented in October 1953. The plans preserved at the FLC's archive detail the general water pipes and the design of the heating coils inside of all the apartments and common rooms, which were called *Panneaux de sol*¹²⁵. Furthermore, the plans do not represent any kind of pipes at the transitional spaces, such as the corridor or the hall on the ground floor, because they were not conditioned.

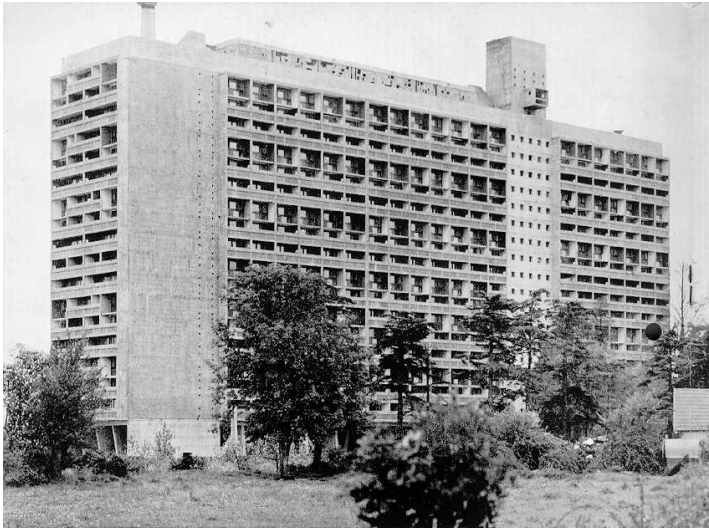
Once the foundations, the *pilotis* and the *Sol artificiel* were built, the workers of *Ets Missenard-Quint* began their works on the first floor in January 1954¹²⁶. On 22 March 1954¹²⁷, Dusseris wrote to the CEEMTP and the *Atelier 35S* to inform of several issues appearing in the coils due to the concrete dosage and the reinforcing rods. After several phone calls, Wogensky sent an information letter for all the contractors paying special attention to the concrete dosage (300 kg/m³ of cement) and to the concrete cover for the pipes (at least 1 cm)¹²⁸.

In December 1954¹²⁹, the work's manager noticed the perforation risk on the coils of several apartments due to the partitioning execution procedure. In order to prevent future problems, Dusseris advised to the owners to make it fixed by the general contractor using the sectioning valves to isolate the affected coils¹³⁰. After this, the works continued without important events until they were finishing the construction in July 1955.

At the period, the attention paid by architects and engineers in this work to provide comfort in terms of acoustics and temperature was really exceptional. Apart from the thermal services, they implemented the double isolating glass for the numerous windows of the apartments according to the patent *Thermopane*. Besides, the partitions between apartments were done by light concrete with vermiculite, which improved their performance in acoustic insulation.

The original installation was subject to of several analyses, maintenance operations and works but the scheme of the system remained the same. In 1982, a thermal diagnostic of the boiler led to its complete recasting. In 1983, an integral analysis of the building, aimed to organize the refurbishment works and throw light on the problem of the coils' corrosion process. As the report states: "*l'amélioration du système de chauffage pour résoudre la corrosion latent des tuyauteries*" (Bataille and Pinson 1990). Lastly, in 1986, once the works were done and following the impossibility of intervening on the coils, the works manager explained the main problem: "*c'est aussi une problème technique [...] on a des serpentins de chauffage noyés dans le sol, on ne sait pas trop où ils sont, il n'est pas question de venir taper dedans*".

Nowadays, personal discussions with the inhabitants confirm that the heating system is still working. The installation, in contrast, was designed for an automatic regulation of indoor temperature adapted to 18°C according to the exterior climate and nowadays the thermal comfort criteria has generally changed. No temperature regulation was previewed inside the apartments, so inhabitants cannot adapt the heated-slab to their personal comfort. Consequently, the gradual loss of efficiency, due to the continuous obstruction of the pipes throughout the years, has led to the increase of heating sources to condition the apartments, such as thermo-convectors or warm air heaters.



UNITÉ D'HABITATION LE CO

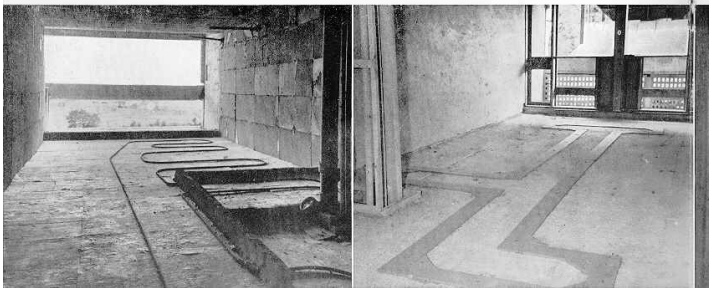


Figure 23. Ets Missenard Quint ad (FLC Q1-15-217)



Figure 24. Apartment's coil (FLC L3-1-21c)



Figure 25. Apartment's coil (FLC L3-1-22)

NOTES:

- ¹⁰⁹ FLC 2504. Conditionnement d'air, coupe transversale. Gardien 12/02/1951. 1:100. Crayon noir. Calque épais. 0.32x0.75.
- ¹¹⁰ FLC 02528: Schéma général de conditionnement d'air"
- ¹¹¹ Quote cf. Monnier (2005).
- ¹¹² A. Wogenscky, letter to Ets Missenard-Quint, 9 January 1953, FLC E3.3.15.
- ¹¹³ A. Wogenscky, letter to Ets Neu – Carrier – Ets Missenard-Quin, 11 February 1953, FLC E3.3.130.
- ¹¹⁴ A. Wogenscky, "Unité d'habitation de Nantes-Rezé. Lot Se – Revêtement de sol", 5 March 1953, FLC E3.3.179.
- ¹¹⁵ A. Wogenscky, FLC E3.3.179.
- ¹¹⁶ B. Morel (Ets Missenard-Quint), letter to A. Wogenscky, 27 February 1953, FLC N4.1.38.
- ¹¹⁷ A. Wogenscky, "Unité d'habitation de Nantes-Rezé. Lot So – Revêtement de sol", 6 March 1953, FLC N4.8.457.
- ¹¹⁸ P. Dusseris (Ets Missenard-Quint), "Unité d'habitation de Nantes-Rezé. Lot So – Revêtement de sol", 10 March 1953, FLC N4.1.43.
- ¹¹⁹ A. Wogenscky, "Unité d'habitation de Nantes-Rezé. Essais de plancher chauffant", 15 April 1953, FLC N4.1.117.
- ¹²⁰ P. Dusseris (Ets Missenard-Quint), "Immeuble de Nantes-Rezé", 21 July 1953, FLC N4.1.68.
- ¹²¹ P. Dusseris (Ets Missenard-Quint), "Essais de dalles chauffantes destinées à l'immeuble de Nantes-Rezé", 7 September 1953, FLC N4.1.74.
- ¹²² G. Morel (Ets Missenard-Quint), "Nantes-Rezé", 28 September 1953, FLC N4.1.79.
- ¹²³ P. Dusseris (Ets Missenard-Quint), "Essai d'une dalle chauffante système Missenard", 19 October 1953.
- ¹²⁴ A. Wogenscky, "Unité d'habitation Nantes-Rezé. Essai de dalle chauffante", 31 December 1953, FLC N4.1.109.
- ¹²⁵ Ets Missenard-Quint, Project plans, FLC N5.20.146 to N5.20.151.
- ¹²⁶ P. Dusseris (Ets Missenard-Quint), "Immeuble Nantes-Rezé", 4 Janvier 1954, FLC N4.1.110.
- ¹²⁷ P. Dusseris (Ets Missenard-Quint), "2955-Nantes-PD/RB", 22 March 1954, FLC N4.1.136.
- ¹²⁸ A. Wogenscky, "Unité d'habitation Nantes-Rezé", 8 July 1954, FLC E3.5.147.
- ¹²⁹ P. Dusseris (Ets Missenard-Quint), "La Maison Familiale Nantes-Rezé", 21 December 1954, FLC N4.1.199.
- ¹³⁰ P. Dusseris (Ets Missenard-Quint), "La Maison Familiale Nantes-Rezé", 21 December 1954, FLC N4.1.199.

MAISON DU BRÉSIL, PARIS, 1953-59

The project of the *Maison du Brésil* (Paris, 1953-1959) at the *Cité Internationale Universitaire de Paris* (CIUP) followed the collaboration path proved in the projects of the *Maisons Jaoul* and the *Unité d'habitation*. Even if the project could be a reproduction of the previous experiences¹³¹, it became a new step in their experiments on thermal comfort, helping to understand previous and subsequent projects.

As Demillac (2011) and Requena-Ruiz (2011) state, the very origin of the project was in 1952, when the Brazilian government commissioned the construction of a hall of residence for Brazilian students in Paris to Lucio Costa. The intervention of the *Atelier 35S* began on 14 May 1954, starting a long process of discussion and troubles between the architects as well as negotiations with the CIUP and the Brazilian government, which finally delayed the beginning of the works. In this context, the first evidence of contact with the *Ets Missenard-Quint* appears on 25 July 1957 in a file that includes the contract signed with Madureira de Pinho¹³², the project report¹³³ and the particular conditions of the works¹³⁴.

The early proposal of the engineers was based on a scheme that combined three different strategies. Firstly, a heated-slab system that would produce the base temperature for most of the spaces of the building. It was according to the details of their own patent, as the report proof: "*Système Missenard, alimentés en eau chaude à température normale 97/70 à 20°C*". In addition, the project includes a standard 1:1 section dated on 11th February 1953, which represented all the materials and layers description¹³⁵.

Secondly, the residential area would be complemented in their first and fifth floors' with a network of convectors in order to balance out the heat losses due to their greater exposure. The same system was also suggested for the small rooms and for the director's house, where as they stated the surface of floor was not enough to heat inhabitants. Lastly, the ground floor theatre was designed with a blown air heater, which was adapted to the intermittent use of the room allowing a fast thermal conditioning of the space (Gargiani and Rosellini 2011, 524).

The report even specified the range of resultant temperatures in the main zones of the building. For the rooms levels, the engineers proposed 18°C in the rooms and no heating in the indoor corridors. The reason for this was not explained, but it could be due to their low heat losses, to an intention of achieving a lower temperature to create a thermal transition, or to the lively character of the expected activities. All of them were parameters commonly studied by Missenard to determine thermal comfort conditions. The project shows a heated-slab working at 15°C for the hall. The small glazed entry box that constituted the threshold inside-outside was not heated. Finally, the theatre would be heated up to 18°C, which could also be related to the passive activity of the users.

All this richness in thermal atmospheres does not seem to be evidenced in the previous projects and it can be explained by Missenard's physiological thought in his theoretical books. The project description and the plans seem to reflect a complex approach to the heating system, which could be understood as a basic materialization of his theory of thermo-regulation training¹³⁶. However, neither architects nor engineers stated it from this angle in the documents studied.

For the ventilation and heat dissipation in summertime, the architects conceived two strategies based on their Indian experience. The ground floor would be equipped with eight *aérateurs*, whose positions in the *pan-de-verre* façades were apparently chosen to favour cross-ventilation, especially throughout the main hall. In the case of the rooms, they only would be provided with one *aérateur* in the main façade, which was the entry vent and a second interior *aérateur*. This would be connected with a vertical conduction up to a roof chimney rigged with a fan¹³⁷. This plan, which had been previously developed for the *Secretariat* of Chandigarh, resulted from the disagreement of the CIUP with the cross-ventilation running through common spaces, corridors and kitchens because of the fire risk.

From March to May 1958, all project plans appeared to be finished, detailing the circuits of the radiant floor heating system¹³⁸ and the complementary devices (convectors and radiators)¹³⁹. The project preserved at the archives also includes a sketch of the heated-slab that explains the Missenard patent¹⁴⁰.

The workers of *Ets Missenard-Quint* began their intervention in the *Maison du Brésil* worksite in May 1958¹⁴¹ installing heating pipes diameter 19/21 mm for the heated-slab on the ground floor. The following reports of monthly advancement reveal a regular evolution of the works until 11th July 1959¹⁴², when Gardien informed the engineers of a leak in a coil on the ground floor. Following this event, on 25th September 1959¹⁴³, the *Ets Missenard-Quint* sent an invoice for repairing the leak, explaining that they did not assume the responsibility because the leak was done by punch blows. Consequently, the *Maison du Brésil* paid the engineering firm to get it repaired.

On the contrary to what happened at the *Unité d'Habitation* in Rezé, there are no pictures of the construction of the heated-slab in the FLC archives. Although there are pictures of the entire building process (structure, façade, partitions and roof), there is no graphical evidence of the heating system construction.

As in the previous work, the floor took a special relevance in this case. The flooring materials were not only important from an aesthetic viewpoint but more in a sensory approach to the space. Only environmental techniques like the radiant floor heating system allowed for the building of complex spaces like the ground floor hall, with its curved walls and glazing that changed the conventional interior-exterior definition. A special attention was therefore paid to the flooring materials technic and aesthetic properties according to each space. On the room levels, two synthetic floors were budgeted, the *Viniflex* by *Société La Callendrite*¹⁴⁴ and the *Bulgomme* by *Société Chevalier*¹⁴⁵. On the ground floor, the flooring was exquisitely composed in parallel strips of black slate sheets, estimated by *Goring et Burel*¹⁴⁶. All of them contributed to the thermal atmosphere of the place and at the same time gives visual relevance to the thermal source.

The main troubles in this work arrived for the last phase of the works and the reception by the users. On 7th October 1959¹⁴⁷, the director of the *Maison du Brésil* complained to the *Atelier 35S* because of the delay in the finishing of the heating and ventilation systems and he also enclosed a report of the engineer of the CIUP with a list of issues to finish. On 23rd October¹⁴⁸, the engineers answered to the architect's office explaining that the reason for the dysfunctionment of the heating system was the fuel supply, "*le fluide chauffant venant de la centrale*". A subsequent visit of Gardien and Presente to the engineers' office led to a second analysis of the installation. On 30th

October 1959¹⁴⁹, they answered that they had visited the installation and they had verified that the boiler temperature was fixed to produce 19°C in the spaces but they could not analyse the mean temperature in the spaces because the fuel service was not continuous and the boilers stopped often.

A variety of other minor operative and comfort problems were solved until the final acceptance of the entire heating system on 6th October 1961. For instance, on 14th January 1960 the architects informed the engineers that Leonidas Porto, director of the *Maison du Brésil*, had complained because of a bad adjustment of the auditorium air heating system, which hindered the students from meeting in the space¹⁵⁰. Due to this but also for economical and administrative issues evidenced in the letters, the final reception of the entire heating system was delayed. On 6th October 1961¹⁵¹, the director accepted the heating system installation, although the work of *Ets Missenard-Quint* were not finished because on 30th October 1960¹⁵² Portos complained for the reason of the inefficiency of the heating system on the first floor of the director's house.

Paradoxically, in 1962 the engineering company was requested by the *Maison de Brésil* to develop the project for the heating system of the residence extension, designed for Le Corbusier as well. They finally refused to take part in the project in a letter on 28th February 1962¹⁵³.

Once they installation was operating, then the thermal comfort troubles started for the inhabitants, which is an issue that has been continuous until today. The designers did not specifically deal with the various climatic cultures and practices of Brazilians, as well as their adaption to the Parisian climate. The users coming from a warm climate region and the low operative temperature according to Missenard's researches demonstrated not to be compatible with it. This issue led to a massive use of electric convectors to heat the rooms, which was not supported by the original electrical installation (Karam Brum 2009). Besides, the residents understood that low temperatures were related to the *aérateurs* leaks, so they blocked them, which triggered condensation problems at the showers.

During the renovation works in the 1990s, the engineers studied the heating coils in the rooms and they discovered that the high temperature of the water, due to the low density of pipes, had produced lime accumulations that had almost sealed the heating pipes. Consequently, they decided to introduce radiators in all the rooms according to those originally installed in the first and fifth floors, as well as to seal definitively the heated-slab. The same problem was found in the heating coils at the ground floor. Thus, the renovation team decided to seal the heating coils and to install at the base of the *pan-de-verre* a line of warm-air blowers in the thickness of the stone flooring¹⁵⁴.

Currently, the residents are still manifesting problems regarding to thermal comfort. As Karam Brum (2011) states, the inhabitants coming from North and South Brazil have different perceptions of the temperature of the heating system, which currently achieves average temperatures about 26°C. However, the current difficulty to produce cross-ventilations in summer triggers particular uses of the shaded spaces and comfort troubles because of the average indoor temperatures of 32°C (Requena Ruiz 2013).

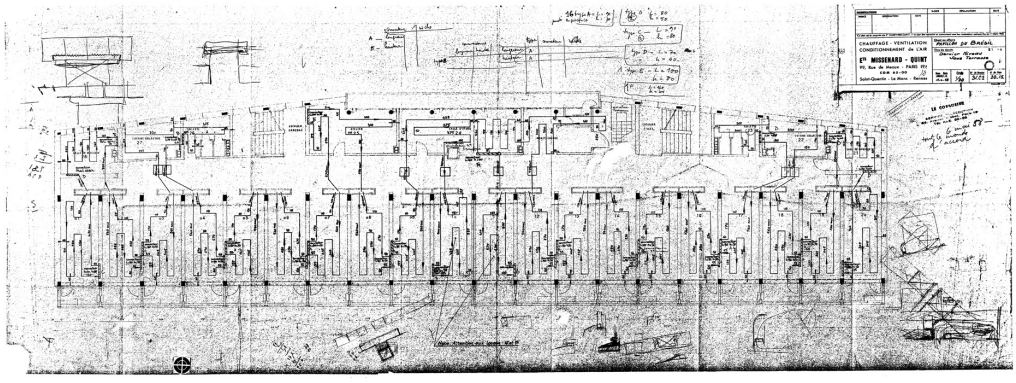


Figure 26. Room's floor heated-slab (FLC K1-9-6)

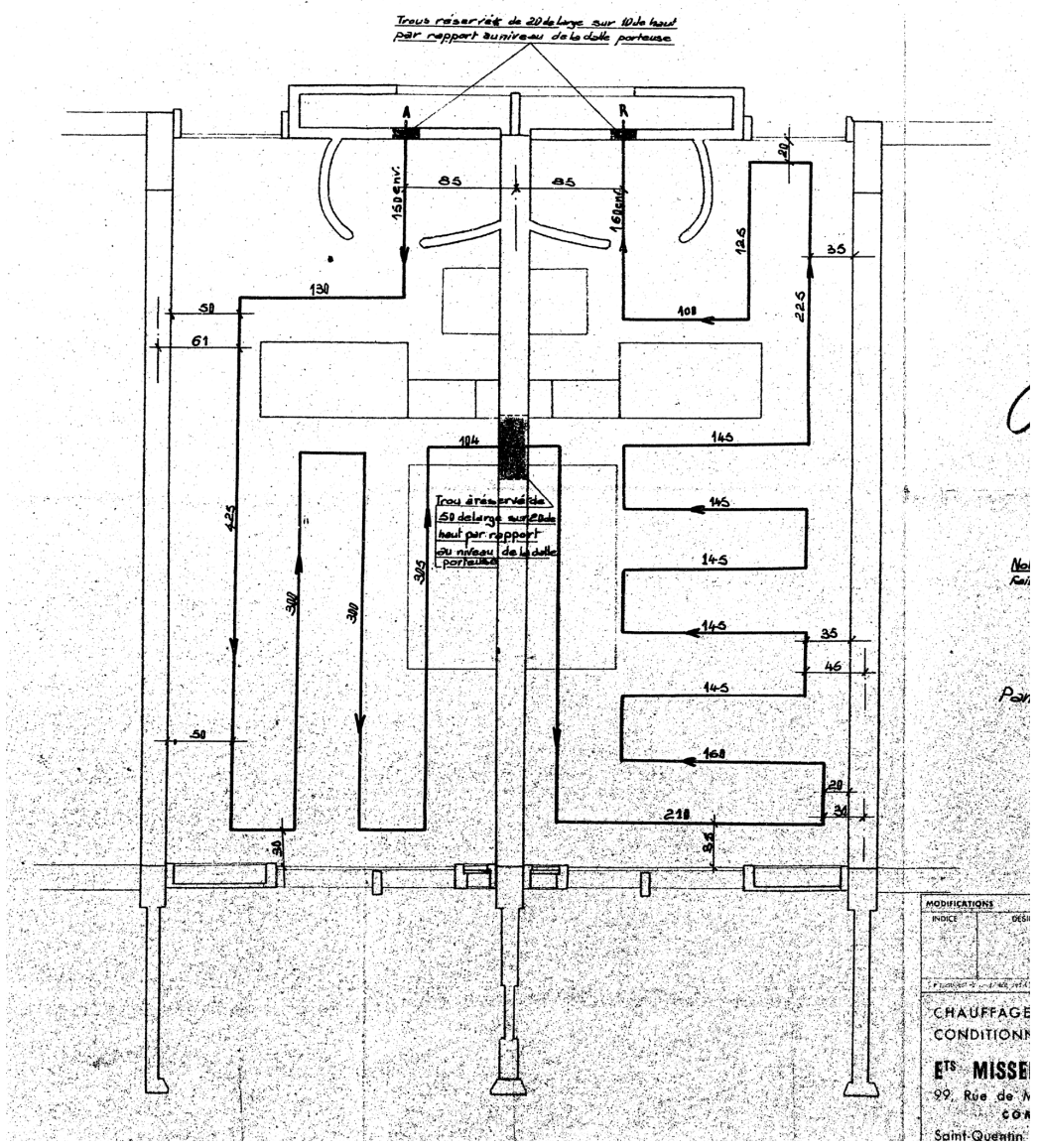


Figure 27. Room's heated-slab plan (FLC K1-9-11)

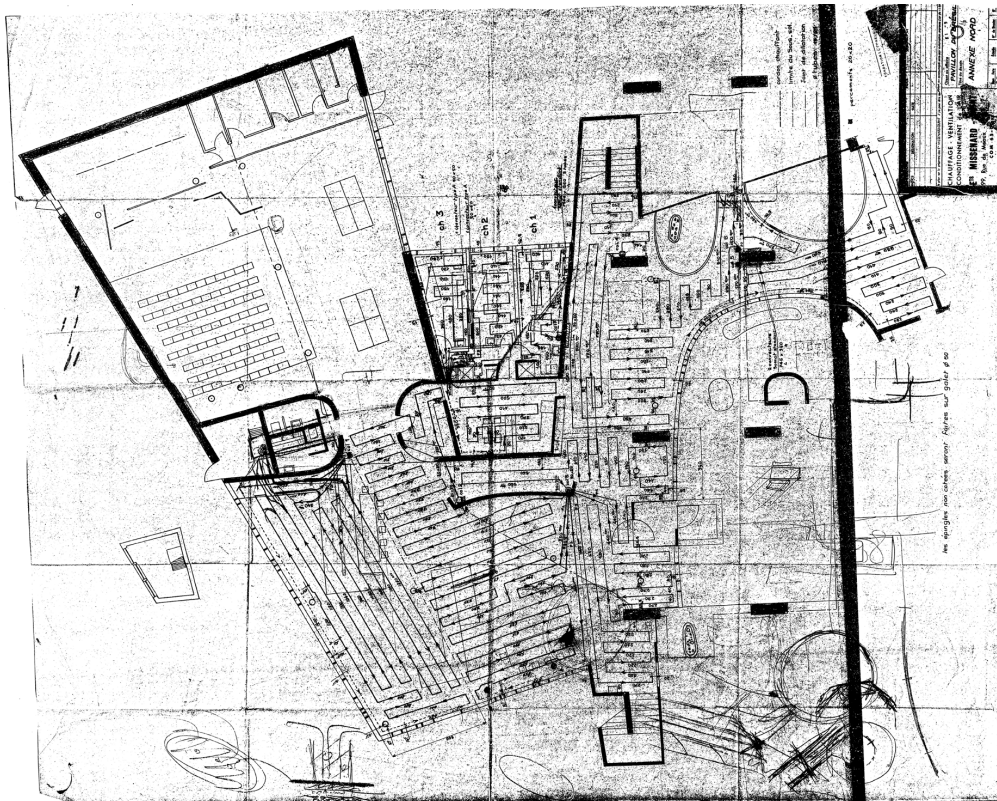


Figure 28. Ground floor heated-slab (FLC K1-9-16)

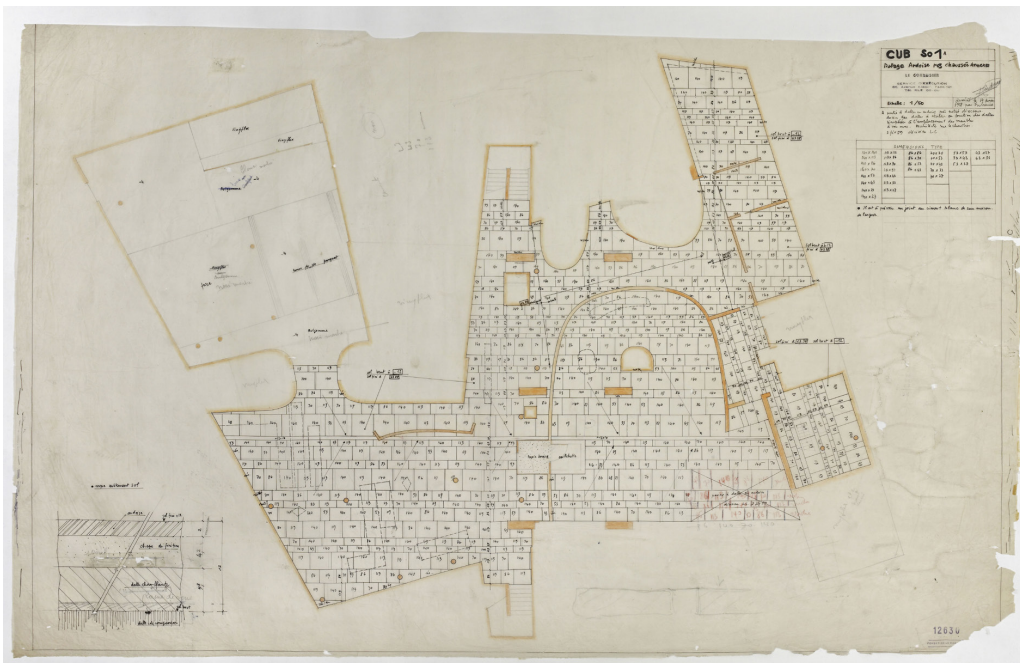


Figure 29. Slates composition in the ground floor (FLC 12630)

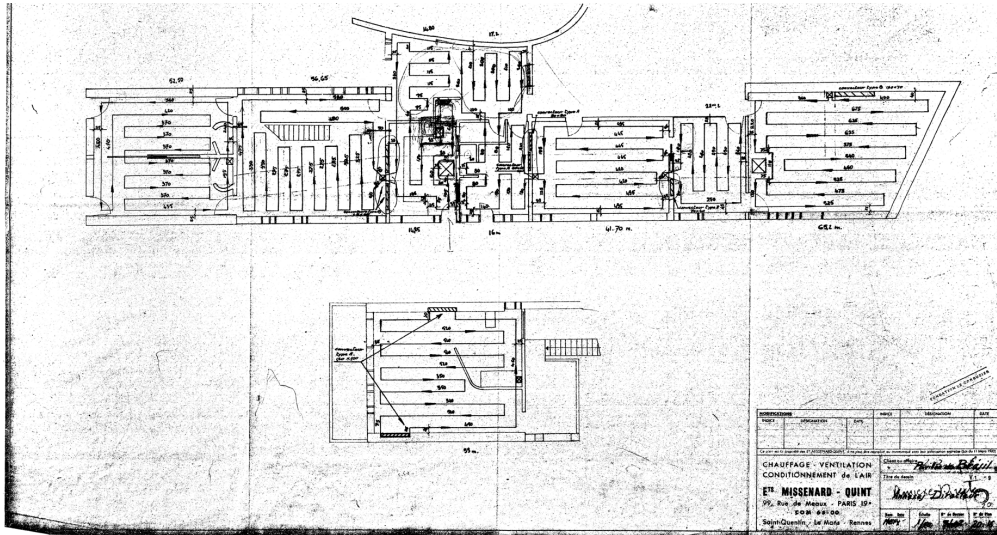


Figure 30. Heated-slab plan at the director's apartment (FLC K1-9-20)



Figure 31. Ground floor (FLC 8725)



Figure 32. Ground floor (FLC 8710)



Figure 33. Ground floor (FLC 8716)



Figure 34. Ground floor (FLC 8719)

NOTES:

- 131 The system seemed to be integrated into Le Corbusier's procedures, so there is no photo in the FLC archive that reflects the construction process.
- 132 Ets Missenard-Quint, "Marché pour les travaux de chauffage et ventilation", 25 July 1957, FLC K1.5.265.
- 133 Ets Missenard-Quint, "Devis descriptif des travaux", 25 July 1957, FLC K1.5.277.
- 134 Ets Missenard-Quint, "Cahier des charges et conditions", 25 July 1957, FLC K1.5.269.
- 135 Ets Missenard-Quint, "Panneau Rayonnant de Sol. Brevete A. Missenard (R.C.S.). Coupe de la dalle chauffante", 11 February 1953, FLC K2.6.296.
- 136 The plans of the heating systems for the ground floor (K1.9.12) and the room floors (K1-9-16) as well as in the heating system description (K1.5.277), gives evidence of this.
- 137 Le Corbusier, letter to P. Jeanneret at the Punjab, 22 May 1956, FLC P1.10.306.
- 138 From FLC K1.9.5 to K1.9.21
- 139 From FLC K1.9.1 to K1.9.5
- 140 Ets Missenard Quint, "Esquisse dalle chauffante", n.d., FLC K1.9.34.
- 141 Le Corbusier and Andreini, "Maison du Brésil à la Cité Universitaire de Paris. Situation n° 1", 30 May 1958, FLC K1.12.233.
- 142 Gardien et Presente, letter to Ets Missenard-Quint, 11 July 1959, FLC K2.6.171.
- 143 Ets Missenard-Quint, "Facture 4592", 25 September 1959, FLC K1.16.324.
- 144 Société La Callendrite, "Dévis revêtement des sols Viniflex", 1957, FLC K2.10.1
- 145 Société Chevalier, "Dévis revêtement des sols Bulgomme", 1958, FLC K2.10.49
- 146 Goring et Burel, "Dévis revêtement des sols d'ardoise", 1958, FLC K2.10.81
- 147 B. J. Alves (Maison du Brésil), letter to Atelier Le Corbusier, 7 October 1959, FLC K2.6.190
- 148 Ets Missenard-Quint, letter to the Atelier Le Corbusier, 23 October 1959, FLC K2.6.200.
- 149 F. Gardien (Cabinet Presente), letter to Atelier Le Corbusier, 26 October 1959, FLC K2.4.575.
- 150 Le Corbusier and F. Gardien, "La Maison du Brésil à la Cité Universitaire de Paris. Chauffage", 14 January 1960, FLC E3.14.8.
- 151 F. Gardien, "Certificat de reception definitive", 6 October 1961, FLC K1.16.331.
- 152 Leonidas Portos (Director of the Maisson du Brésil), Letter to Morel (Ets Missenard-Quint), 30 October 1960, FLC K2.6.273.
- 153 M. Missenard, "MG – Agrandissement de la Maison du Brésil", 28 February 1964, FLC K1.4.82.
- 154 The comments of the renovation works resulted from a conversation with the architect Bernard Bouchet, director of the renovation works.

UNITE D'HABITATION, BRIEY-EN-FORET, 1956-60

The project for the third of the five *Unités d'habitation* required a greater struggle for completely adapting Rezé's scheme to the actual HLM requirements. As Marza and Tinacci (2011) report, the housing typologies and the aggregative logic of the cells were not changed, although the number of small apartments facing only one façade increased. The economical restrictions imposed the elimination of the public services floor once again, repeating what Le Corbusier considered a mistake in Rezé: "*la suppression totale des locaux commerciaux à l'intérieur du bâtiment*".

Like previously happened, the first call for applications finished with the non-conformity of the jury because the companies exceeded the budget. Then, they decided to open a second call for applications that was followed by the jury session at the end of 1957. The jury once again enhanced the know-how in experimental HLM constructions, what led to the choice of several of the companies involved in Rezé's works: the company CEEMTP was in charge of the concrete flowing and the works management; *Barberis* produced and installed the carpentries; *Alazard* produced the windows; *Ets Missenard-Quint* was responsible for the heating and ventilation systems; *Séchaud & Metz* were once again given the role of technical coordinators. Finally, Wogenscky was the *architecte d'opération* and Le Corbusier was the head of the group.

Marza and Tinacci (2011) explain how the last proposals submitted by these companies reduced the construction quality for cost saving, even in aspects considered fundamental by Le Corbusier. These changes mainly affected to the acoustic insulation of slabs and walls, as well as the substitution of the floating floor slab (acoustics and heating system) by a regular massive 13 cm thick slab with the heating system coils embedded.

The collaboration with *Ets Missenard-Quint* for the project of Briey started on 19th December 1956¹⁵⁵, when they submitted to the *Atelier Wogenscky* a technical report for the heating system of an *Ensemble d'Habitations* in Briey. They also included a global estimation of the heat losses for several buildings based on the plan FLC 5337C, although they did not detailed the heating system proposal. This file constitutes the most detailed file of the Missenard's company preserved at the FLC's archive.

THE APPLICATION FILE OF JUNE 1957

On 29 June 1957, *Ets Missenard-Quint* sent a complete report of the heating system to the *Office Publique d'Habitation à Loyer Modéré*. This file is stored with shelf numbers Q1.15.173-259. First of all, the documents from Q1.15.173¹⁵⁶ to Q1.15.178 correspond to the submission letters and the budget explanation for the two proposals of the engineers: "*solution système Missenard*" and "*solution variante dalle pleine*". According to the documents, they argued in favour of the latter because it saved in construction costs in comparison with the former.

The technical report (Q1.15.180)¹⁵⁷ starts with a general description of the building's heating and ventilation systems: "*L'installation de chauffage a été traitée par panneaux rayonnants de sol. L'installation de ventilation des cuisines, W.C. et douches est conforme au cahier des charges. La ventilation comprend un réseau de gaines passant dans les trémies et débouchant dans le collecteur supérieur, aux extrémités duquel sont installés deux ventilateurs centrifuges d'aspiration*". The final proposal, however, was not decided yet. At the end of this first summary the engineers detailed two different installations:

“l'installation de chauffage par rayonnement est présentée suivant deux solutions: 1) une solution de base où l'on utilise le système MISSENARD à température normale 90°, identique à la solution adoptée pour l'unité de NANTES REZÉ ; 2) une variante en chauffage par rayonnement simultané par le sol et le plafond au moyen de serpentins à basse température enrobés dans une dalle pleine”. The engineers explained afterwards that both systems had the same advantages in terms of heating and the result would also be the same because the surface heated would be identical.

In the same way, they offered two choices for the regulation of the water temperature in the circuits of coils: *“le départ des circuits comprend une ou plusieurs régulations suivant les solutions. En effet, nous vous présentons : 1) En solution de base, une régulation unique pour l'ensemble de l'installation ; 2) En variante, une régulation unique et une régulation par façade”.* The second proposal, which would use three circuits to adapt to the different heat losses and gains of each of the three façades (East, West and South), had been previously tested in the *Unité d'habitation* in Rezé and in the *Maison du Brésil* in Paris. As they explained below, each circuit would have a regulation system composed by a motorized valve, a flow sensor, an outdoor sensor and a regulator.

The report also includes a general description of a radiant heating system and its benefits, which actually was signed on 17th January:

La température résultante est le repère de la sensation de confort d'un individu, en tenant compte des échanges thermiques avec l'ambiance et les parois par convection et rayonnement [...] La température résultante correspondant au confort généralement admis en France pour les locaux d'habitation et les bureaux est de 17° [...] Le chauffage par rayonnement est un procédé de chauffage qui, à égalité de température de l'air, donne une température résultante supérieure à celle que l'on obtient dans un chauffage classique [...] Les surfaces chauffantes d'une installation de chauffage par rayonnement sont caractérisées par leurs grandes dimensions apparentes et leur température relativement basse.

Finally, the report detailed the two proposals for the heated-slab that were previously sketched out.

CHAUFFAGE PAR LE SOL À TEMPERATURE NORMALE ET À ENROBAGE HETEROGENE [...] L'idée qui a présidé à la théorie du système breveté MISSENARD, dit chauffage par le sol à température normale, était d'obtenir simultanément un prix de revient moins élevé de l'installation grâce à une régularité parfaite des températures de surfaces. Ces deux résultats, en apparence contradictoires, ont été atteints grâce à un enrobage hétérogène, comportant en plus du béton habituel, des bandes de matériau isolant situées au-dessus des tubes chauffants; par la mise en place de

ces bandes, la résistance thermique entre le tube et un point quelconque du sol est pratiquement constante. On peut ainsi réaliser un chauffage avec des tubes espacés de 50 cm, les bandes isolantes ayant, suivant la nature du revêtement, une largeur de 8 à 18 cm [...] Le chauffage par le sol à température normale et enrobage hétérogène (brevet Missenard) est exploité en Europe par les Groupement International de la Richard CRITTAL, STRALINGSWARMTE, qui est la plus puissante dans le monde et qui englobe en France une cinquantaine d'installateurs comportant les Maisons les plus importants du marché [...]

NOTE SUR LE CHAUFFAGE SIMULTANE PAR LE SOL ET LE PLAFOND au moyen de serpentins à basse température enrobés dans une dalle pleine [...] Un procédé de chauffage particulièrement économique et d'un excellent rendement peut être réalisé en accord avec l'Entreprise de gros œuvre, si celle-ci peut utiliser comme plancher des dalles pleines préfabriqués ou non [...] Les tubes de chauffage sont attachés au-dessus de ce ferrailage, la partie supérieure de la dalle, après surfacage, reçoit directement le revêtement, qui peut être du linoléum, du Dalami, du parquet.

The following document included in the file that was entitled *Codes des conditions*, dated June 1955¹⁵⁸. It is a copy of the summary of the constructive conditions for heated floors in concrete with coils embedded in an independent slab.

The last four documents are constituted by four publicity leaflets where *Ets Missenard-Quint* took advantage of their collaborations with the *Atelier 35S* for enhancing their experience in this sort of construction. The file begins with a cover letter entitled "*Quelques Références (de 1928 à 1954)*"¹⁵⁹. Actually, it seems to be a collection of references attached to their application for the construction of the heating system. Three leaflets are preserved in this file.

Firstly, the leaflet for radiant heating systems (ceiling and floor)¹⁶⁰ in which the *Unité d'habitation* in Rezé-les-Nantes was a realization example. The pictures of the finished building are mixed with pictures of the execution of Missenard's patent for the radiant floor heating system. The text pays attention to all the parts of the space conditioning system like thermal insulation, automatic temperature regulation or hygienic ventilation. All the information seems to enhance the innovative character of their techniques in parallel to their feasibility.

Tous les locaux sont chauffés par le sol à la température normale d'eau. La dalle chauffante étant posée sur une couche de laine de verre balisée et participant ainsi à l'insonorisation du bâtiment [...] les températures sont réglées par une armoire

électronique en fonction de la température extérieure [...] Une réseau de gagnes permet [...] assure la ventilation des pièces.¹⁶¹

Secondly, the cover of another leaflet is preserved. It was used by the company to guarantee their experience in radiant floor heating systems by comparing the entire surface where they had installed their systems to the surface of the city of Reims, which appears in a big aerial picture.

The last leaflet¹⁶² has only the slogan “*Nouvelles techniques des Climats artificiels. Etablissements Missenard-Quint*” written on it. It is interesting the use of the expression ‘Artificial Climates’ in advertising and the two pictures that accompany the message. The one above shows a shelter with long ice stalactites in the middle of a snowy mountain, whereas the picture below illustrates a palm tree plantation in a sunny day. The pair of pictures recalls two different approaches to the artificial climates technique: it could protect us from every climatic condition (the warmest summer and the coldest winter); or, it could create or reproduce every climate that you can imagine (the tropic and the mountains).

THE FINAL PROJECT AND THE BUILDING PROCESS

On 4th December 1957¹⁶³, Wogenscky informed Dusseris of his discussion with CEEMTP about the two proposals for the heating system. Their conclusion was to choose the heated-slab integrated in the structure, so he wanted more details on the “*chauffage qui serait intégré dans la dalle pleine de 13 cm d’épaisseur*”. The answer of Dusseris on 13th December 1957¹⁶⁴ explained the construction details of this particular type of slab.

Although all the process seemed to be clear, the final project was delayed until 13th October 1958, when *Ets Missenard-Quint* sent to the Council of Briey the report of particular specifications (Q1.18.21), the budget estimation (Q1.18.30), the technical report (Q1.18.34) and they signed the contract for the works (Q1.18.43).

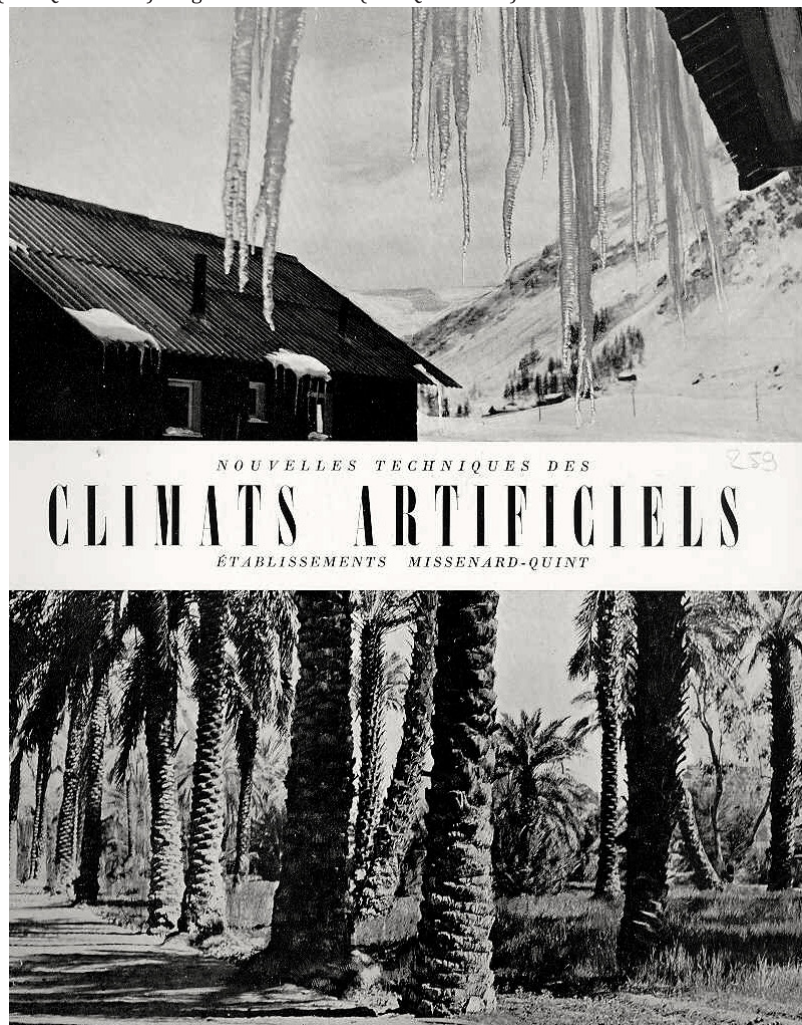
The technical report¹⁶⁵ is clearly based on the previous one of June 1957, although they made the decisions on the proposals previously suggested. On the one hand, as the previous letter shows well, they opted for a heating system designed by embedding the heating coils in the structural slab of reinforced concrete. On the other hand, the automatism for the temperature regulation used only a main regulator, which depended of an outdoor and indoor temperatures calibration.

On 1st February 1959¹⁶⁶ Lavot, a collaborator of the *Atelier Wogenscky*, wrote a letter to the engineers asking for a report of the eventual dilatation effects of this heated-slab solution on the structural slab. Consequently, Dusseris answered to Lavot in order to calm him down explaining the low temperatures of the heated water at the coils.

During April of 1959, the workers of the *Ets Missenard-Quint* started the installation of the heating coils in the slabs. The epistolary exchange shows that the works had no interruption or big issues until the end of their works in the July 1960.

Such as in the previous cases, regulation troubles appeared after the installation was delivered. On 9 November 1961¹⁶⁷, after finishing the construction, when the first inhabitants were occupying their apartments, *Ets Missenard-Quint* received a letter complaining for the wrong thermal regulation of the system. Consequently, the temperatures between apartments oscillated from 15°C to 24°C.

Last of all, on 9th July 1962¹⁶⁸ the company sent a mail to the Council of Briey with two proposals for heating the ground floor. As an extra element, both of them were based on the use of radiators. The answer and the final solution adopted were not found at the FLC archive.



NOTES:

- 155 Ets Missenard-Quint, letter to the Atelier Missenard "Ensemble Briey", 19 December 1956, FLC V1.13.184.
- 156 Ets Missenard-Quint, letter to the Office Publique d'Habitations à Loyer Moderé, 29 Juin 1957, FLC Q1.15.174.
- 157 Ets Missenard-Quint, "Notice technique. Installation de chauffage", 29 Juin 1957, FLC Q1.15.178.
- 158 Ets Missenard-Quint, "Codes des conditions", June 1955, FLC Q1.15.214.
- 159 Ets Missenard-Quint, "Quelques références", n.d., FLC Q1.15.225.
- 160 Ets Missenard-Quint, "Chauffage par rayonnement. Sol-plafond", n.d., FLC Q1.15.217.
- 161 Ets Missenard-Quint, FLC Q1.15.217.
- 162 Ets Missenard-Quint, "Nouvelles techniques des Climats artificielles", n.d., FLC Q1.15.259.
- 163 André Wogenscky, letter to Dusseris (Ets Missenard-Quint), 4 December 1957, FLC V1.13.188.
- 164 Dusseris (Ets Missenard-Quint), letter to the Atelier Wogenscky, 13 December 1957, FLC V1.13.190.
- 165 Ets Missenard-Quint, "Notice technique installation de chauffage", 13 October 1958, FLC Q1.18.34.
- 166 J Lavot (Atelier Wogenscky), letter to Ets Missenard-Quint, 1 February 1959, FLC V1.13.198.
- 167 Office Publique d'Habitations à Loyer Moderé, letter to Ets Missenard-Quint, 9 November 1961, FLC V1.13.339.
- 168 Ets Missenard-Quint, "Hall de l'Unité d'habitation Le Corbusier", 9 July 1962, FLC V1.13.345.

UNITÉ D'HABITATION, FIRMINY, 1959-68

The fifth *Unité d'habitation* building was included in the plan designed and built by Le Corbusier and his collaborators for Firminy. The early sketches for the project appeared on 17th July 1959, although the building was delivered in January 1968, two and a half years after Le Corbusier's death.

The project was subjected to the same budgetary conditions than those of Rezé and Briey-en-Forêt. Consequently, it suffered the aforementioned architectural and constructive changes according to the original prototype of Marseille.

The collaboration of *Ets Missenard-Quint* for the heating system started in March 1963, when they sent a first budget to the architect's office, including a short summary of the installation proposal for Briey-en-Forêt. Subsequently, the correspondence reveals that different minor modifications were operated in the budget and details of the architectural project, such as the "*gaine technique*".

In parallel, several changes of personnel happened in both architect and engineer offices, so the usual members for the projects varied several times. Firstly, at the *Atelier 35S*, Gardien continued in charge of the project at the beginning. He was assisted by Rebutato, who led the project afterwards and eventually also by Jose Oubrerie. Lastly, the office of *Ets Missenard-Quint* was headed from this moment onwards by Michel Missenard, although Betout and Guy Morel mostly dealt with the technical aspects.

Once the project was defined including the engineer's advice, they submitted a report to the *Office Publique d'Habitation à Loyer Modéré* in Firminy on 13 April 1964¹⁶⁹. This document completely defined the elements of the installation and omitted the previous annotations about thermal comfort approaches or different choices for heating and regulation systems that they suggested in Briey-en-Forêt. As they argued, the system would be done with a full heated-slab, taking advantage of the double exposure of the structural slab to radiate heat from the floor and the ceiling to the apartments.

As in the previous case, the temperature of the heating fluid in the coils would be 30°C for 10°C outdoors and 40°C for 0°C outdoors, always limited to a maximum of 50°C. This adaption to the outside temperature was suggested with a single regulation system for all the coils wherever it were placed.

The main difference of this project was the adoption of an urban heating plant for the entire complex, which was designed by the company *Caliqua* specialized in collective installations. The plant was composed by two multi-tube heaters of 7500000 cal/h per heater (Ragot 2011). They produced high-pressure vapour, which was distributed to the buildings' sub-station. *Ets Missenard-Quint*, consequently, did not assume the responsibility of the fluid's temperature, they specified that it was of the company that managed the primary network. In their own words: "*la régulation de la température du fluide chauffante s'effectue à partir d'un ensemble fourni et posé par l'entreprise chargée du réseau primaire*".

Until April 1965, the project plans were progressively evolving without important changes from the first proposal. The documents from FLC N2.7.15 to N2.7.35 dated between May 1965 and December 1967 provides evidence of it.

If the apartments' heating system was generally created according to well-known techniques, the system of the kindergarten at the roof floor was considered apart. The plan FLC 33959¹⁷⁰ corroborates the adoption of both radiant heating panels in the

partitions lines and radiators-convectors placed in a small parapet below the main windows. The radiant heating panels constituted a particular experimentation suggested by the engineering company. As Marino (2014) details, the *Ets Missenard-Quint* took a patent coming from the Polytechnic School of Warsaw (Poland) for a panel system directly connected to the urban heating network. It consisted in a metallic coil embedded in a concrete panel, improving its thermal inertia and its radiating power. The panels were integrated through the use of colour in the spatial proposal of Le Corbusier for the *Ecole Maternelle*.

The foundation stone ceremony that marked the official start of construction works was on 21st May 1965. As the correspondence reveals, *Ets Missenard-Quint* started in September 1965 and continued until March 1968 without major troubles according to the main planning. In effect, the reiteration of most of the techniques already experienced in Rezé and Briey-en-Forêt made easier for the engineers managing all the construction process.

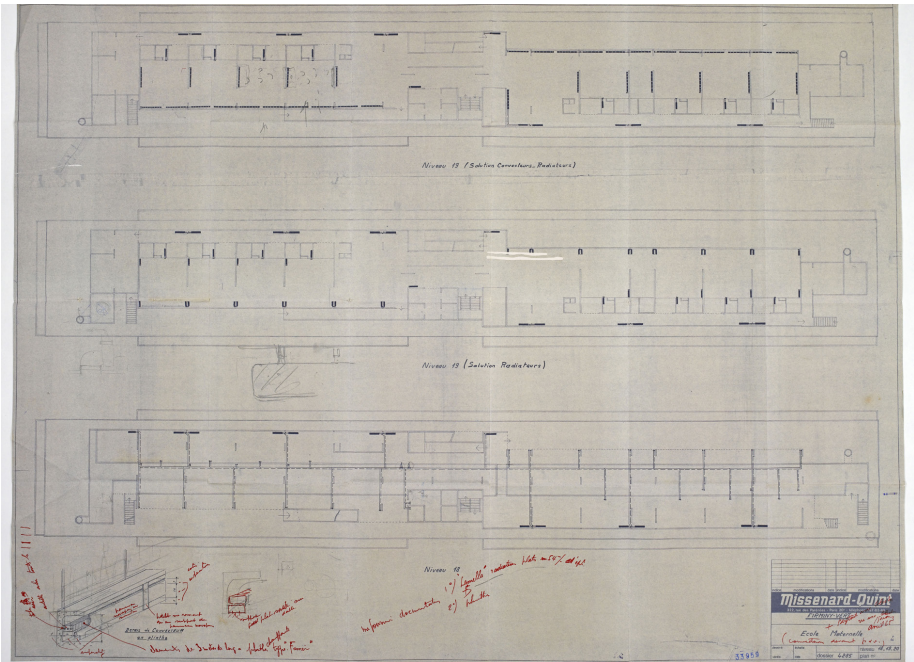


Figure 38. Heating panels distribution in the kindergarten floor (FLC 33959)

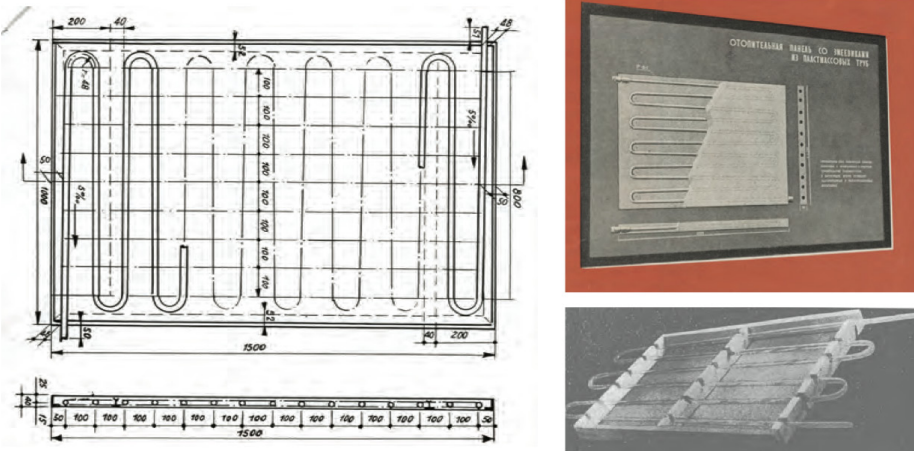


Figure 39. Heating panels in concrete (ITBTP, 1957)



Figure 40. Kindergarten inside pictures. Heating panels in dark blue.

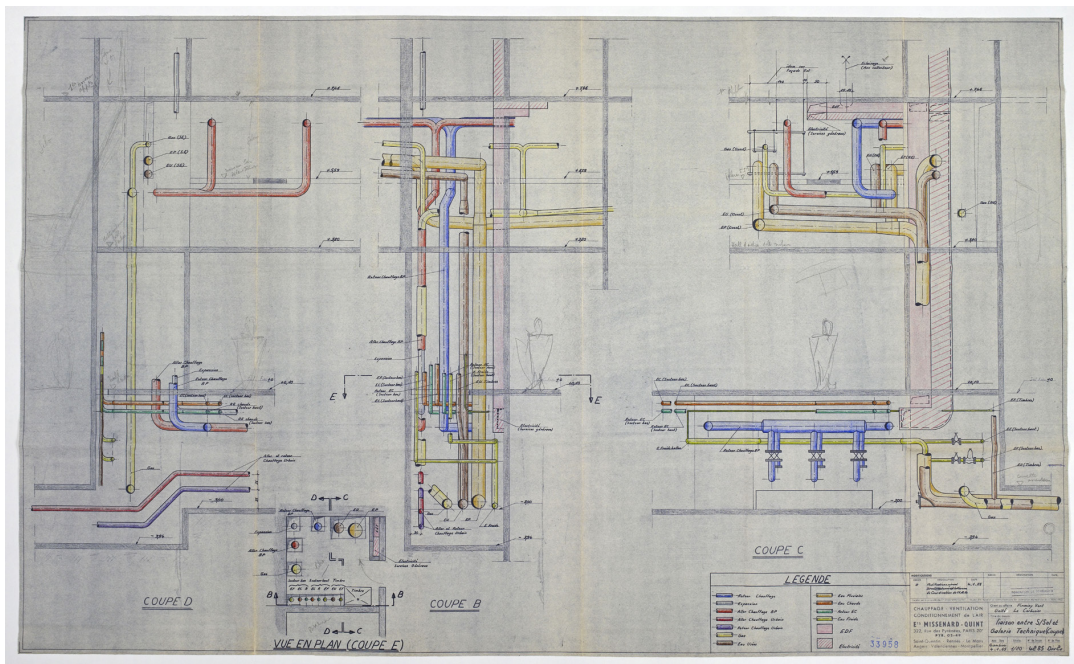


Figure 41. Heating system ducts distribution (FLC 33958)

NOTES:

- 169 Ets Missenard Quint, "Dévis descriptif et estimatif pour l'équipement d'une Unité d'habitation Le Corbusier de 414 logements edifiés à Firminy-Vert", FLC N3.14.93.
- 170 Ets Missenard-Quint, "Ecole Maternelle", April 1965, FLC 33959.

INFLUENCE IN OTHER WORKS

Apart from the previous works, the FLC archive has no other evidence of direct collaboration between Le Corbusier and Missenard. However, the analysis of documents related to thermal comfort issues addressed this research in a variety of projects between the late-1950s and the early-1960s, when the influence of the engineer can be traced. In this sense, the works studied in this report are just those linked with the main research patterns, namely: the *Convent of la Tourette*, the *Western Art National Museum* of Tokyo and the *Olivetti Electronic Calculation Centre*.

COUVENT DE LA TOURETTE, EVEUX-SUR-L'ARBRESLE, 1953-1960

The project and works for the *Convent of Sainte Marie de la Tourette* in Eveux-sur-l'Arbresle were almost simultaneous to works like the *Maison du Brésil*. The conditions of this case, however, prevented the collaboration of *Ets Missenard-Quint*, although they collaborated at the very beginning of the project.

The first document preserved in the FLC archive on this topic was a letter of *Ets Missenard-Quint* addressed to Xenakis on 15th February 1956¹⁷¹. Its aim was to specify the type of air diffusers that they had in mind to install at the refectory of the convent. This assertion reveals that the engineers were working on the project for the heating and ventilation system of the convent. It presumably started with an air blowing system for the common spaces, although given that no other explanation was written, the original scheme for the system suggested by the engineers cannot be figured out.

Despite this early collaboration, the first documents detailing the heating system of the convent were signed by the company *Ets Ravoire* in April 1956¹⁷². The construction company that finally took the responsibility of the works, *Sud-Est Travaux et Constructions*, likely imposed this change. It was a new company that was the building branch of an experienced company in the sector of public works, for instance they had just finished a new dam in the Alps.

After a long project that started in 1953 (Requena Ruiz 2011, 258) and a radical process of budgetary adjustment from May 1955 to January 1956 (Ferro et al. 1987, 37), the building works started in August 1956. Subsequently, the new engineering company sent several reports progressively detailing the heating system from different points, such as the "*Bilan thermique : confort et hygiène*"¹⁷³ or the "*Etude de détermination des K de transmission des parois*"¹⁷⁴. They were complemented with the early sketches and plans that pointed to a scheme that differed from the contributions of Missenard.

The plans signed between September and November 1956 showed an installation that divided the main building's network from the one of the church, like previously happened with the concrete structure. The former was designed such a traditional radiator installation, which were placed behind the windows and whose size was dependent on the calculation of thermal losses through the glass pans. In contrast, the heating for the church was not defined yet.

From February to June 1957, *Ets Ravoire* defined the requirements of each space and detailed the materials and systems to be used. For the brother's cells on the third and fourth floors they chose simple radiators of *Idéal Standard*, placed into a niche specially designed in the lower part of the windows. For the ground, first and second floors they suggested the *Runtal* convectors, located in a line behind all the *pan-de-verre ondulatoire*.

On 22nd June¹⁷⁵, the engineers sent to the father Belaud and to Gardien, who now was working for the *Cabinet Wogenscky*, a report that analysed the economical impact of installing double glazing windows. They argued in favour of installing double-glazing for both cells and spaces with the *pan-de-verre ondulatoire*, although they suggested keeping the same characteristics and dimensions of the radiators. This proposal led to savings of 15620 litres of fuel (3% less in annual consumption), what they concluded that would be enough fuel cost saving to quickly recover the investment. The final choice was, however, to install single-glazing windows for all the façades.

In September 1957, *Ets Ravoire* started their collaboration in the construction of the convent, although the church heating system continued uncertainly defined. On 11 January 1958¹⁷⁶, the engineers wrote to the *Cabinet G.M. Présenté* with their final proposal for the heating of the church zone. From the very beginning of the letter they argued for a heated-slab system according to *Runtal's* patent specifications. *Ets Ravoire* noted that they would not have earnings for this change because their only profit for this work would be the reference to their contribution. The letter was complemented with two plans that detailed the water coils to be placed at the church floor.

The closing report of "*Situation des travaux et approvisionnements des installations de chauffage*" and the last invoice of *Ets Ravoire* were signed in December 1959. The building works were completely finished in September 1960, without noticing particular problems in the heating system.

During the building's life, the low quality of the construction, due to the extreme cost saving in the works, had led to progressive damages because of the humidity and condensation troubles. The reinforced concreted suffered steel carbonisation, the roof waterproofing underlayment was broken and the lack of thermal insulation supposed that the heating system was too expensive to operate. The refurbishment works in 2006-13, however, did not deal with the thermal problem of insulation mainly due to the single-glazed windows.

MUSEE NATIONAL D'ART OCCIDENTAL, TOKYO, 1957-59

From the very beginning of this commission in 1957, Le Corbusier paid special attention to the thermal matters of the building. He envisaged an architecture that completely controlled the indoor climate, although in this case his trigger seemed to be the preservation of the art works rather than the visitor's thermal comfort.

On 15 February 1957¹⁷⁷, Maisonnier wrote to Le Corbusier in order to inform him that the installation would require a particular and specialized engineering consultancy. He pointed out several reasons: the complexity of the installation, the big air volume to be weatherised, the size of the machinery hall and the accuracy entailed for the calculations in order to provide the required temperatures.

On 19 February¹⁷⁸, Maisonnier received a letter from the architect Takamasa Yoshizaka, who was one of the collaborators of Le Corbusier in Tokyo together with Junzo Sakakura and Kunio Maekawa. He answered to some of the questions regarding the air-conditioning's machinery room and the duct's size.

Le Corbusier reacted quickly and wrote a letter on 20th February¹⁷⁹ to Frank McEwen (1907-1994). The architect wanted the reference of a museum in Equatorial Africa that McEwen recalled a long time ago in a discussion. This English artist, teacher and museum administrator reached Paris in the 1920s in order to study primitive art at the

Institut d'Art et d'Archéologie at the Sorbonne. In this period McEwen was personal friend of Picasso, Braque, Matisse, Brancusi and Le Corbusier. He served as Fine Arts Representative of the British Council in Algiers and Paris. In fact the building recalled by McEwen was the *Museum of Salisbury* in Southern Rhodesia. The representative was invited in 1954 by the Southern Rhodesian government to act as consultant in the planning of the national art museum.

Resulting from Le Corbusier's contact, on 19 March 1957 Peter Oldfield from Montgomery & Oldfield, who signed the Museum of Salisbury, wrote to Le Corbusier¹⁸⁰. Their design consisted in a full air-conditioned gallery where the more delicate art works were exhibited. The rest of the building was also completely closed and the air renewal was forced by a ventilation system with clean filtered air. As a complement to the previous letter, Oldfield enclosed the climatic data of Salisbury¹⁸¹, the technical report specifying the use of Carrier's *Weathermaker* system¹⁸² and a copy of an article about the museum written by Alain Jouffroy¹⁸³.

The museum's foundations were laid in March 1958 and the completion of the works was on 28th February 1959. In all this time, no other news has been found regarding the air-conditioning or thermal comfort, which could mean that the entire project was done by an external consultancy in Japan.

OLIVETTI CENTRE DE CALCULS ÉLECTRONIQUES, RHO, 1963

In the context of the new site for the Olivetti Electronic Centre, Le Corbusier wrote a letter to Roberto Olivetti on 14th January 1964¹⁸⁴. The architect wanted to suggest two different ventilation systems for the main building of the laboratories and the offices. As Bodei states (2009, 177), the architect considered the choice of the system important in the early design phases in order to guide the window design.

Le Corbusier proposed two solutions for the research building. Firstly, a proposal that joined together the mechanical indoor climate control with natural ventilation. He called this concept "*transaération*" and it was based on the use of the *aérateurs* to force the cross ventilation effect. The latter, was a proposal associated with the early definition of the "*air exact*" of the 1920s, involving a hermetic closed building with fully mechanical air control. In his own words:

J'ai inventé « l'air exact » vers 1927 qui s'est appelé de suite après, par les Américains, « air conditioned ». Dans le climat de Milan :

1) Il n'est peut-être pas nécessaire de contrôler l'air pendant les douze mois de l'année ?

2) Ou, au contraire, faut-il réchauffer l'air en hiver et refroidir l'air en été ?

Si l'on adopte la solution 1/ on pourrait admettre d'employer l'air naturel à certaines périodes et, par conséquent, admettre pour la respiration à l'intérieur du bâtiment ce que j'ai appelé la « transaération » faisant emploi d' « aérateurs », ouvrant sur le dehors, qui sont incorporés dans le dessin des fenêtres. Le bâtiment ne sera donc pas hermétiquement clos. Si l'on adopte la solution 2/

on admet de fabriquer l'air frais en été et chaud en hiver et les façades doivent être absolument hermétiques.¹⁸⁵

According to Bodei (2009, 181), there is no document with the answer of the company choosing the former or the latter proposal. However, the façade detail of the last project dated 9th June 1964¹⁸⁶ shows the *pan-de-verre ondulatoire* in a similar composition to the *Couvent de la Tourette* and the *Maison du Brésil*. In the same way, several narrow windows were implemented in the drawing, leaving the door open to install the *aérateurs*.

The project was published in the last volume of his *Complete Works*, where the abstract persevered in the environmental qualities of the workrooms. In particular, the cooling of the horizontal zone volume was solved through the use of a garden roof, which seems to be a thermal insulation of the indoor space as they proposed at the *Grille Climatique*. Moreover, the roof included a watering system that had the double use of cooling in hot weather periods and watering the plants. In Le Corbusier words, “*les locaux de travail sont éclairés par une lumière zénithale bien répartie, et il y a, de plus, des plantations et des installations d’irrigation pour la saison chaude qui servent en même temps à l’arrosage des plantes.*”

The project and the correspondence of this project reveal design clues based on Missenard’s collaboration during the 1950s. Even if it was not directly recalled, the references to thermal comfort, ventilation, or conditioning systems were never the same after his collaboration with the engineer.

NOTES:

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- ¹⁷¹ Ets Missenard-Quint, letter to Iannis Xenakis of the Cabinet Le Corbusier, 15 February 1956, FLC K3.7.25.
- ¹⁷² Ets Ravoire, “Installation chauffage”, April 1956, FLC K3.1.10.
- ¹⁷³ Ets Ravoire, “Bilan thermique : confort et hygiène”, FLC K3.1.3.
- ¹⁷⁴ Ets Ravoire, “Etude de détermination des K de transmission des parois”, 22 September 1956, FLC K3.1.12.
- ¹⁷⁵ Ets Ravoire, letter to Gardien of the Cabinet Wogenscky, 22 June 1957, FLC K3.8.46.
- ¹⁷⁶ Ets Ravoire, “Couvent de la Tourette. Chauffage de l’Eglise. Solution plancher chauffant”, 11 January 1958, FLC K3.8.97.
- ¹⁷⁷ A. Maisonnier, letter to Le Corbusier, 15 February 1967, FLC F1.12.466.
- ¹⁷⁸ Tanakawa Iosizaka, letter to the A. Maisonnier (Atelier Le Corbusier), 19 February 1957, FLC F1.12.468.
- ¹⁷⁹ Le Corbusier, letter to Frank McEwen, 20 February 1957, FLC F1.12.469.
- ¹⁸⁰ Peter Oldfield (Montgomery & Oldfield), letter to Le Corbusier, 19 March 1957, FLC F1.12.470.
- ¹⁸¹ Peter Oldfield (Montgomery & Oldfield), enclosed document to F1-12-470 “Climatic Data of Salisbury”, 19 March 1957, FLC F1.12.471.
- ¹⁸² Peter Oldfield (Montgomery & Oldfield), enclosed document to F1-12-470 “Air-conditioning technical report”, 19 March 1957, FLC F1.12.472.
- ¹⁸³ Peter Oldfield (Montgomery & Oldfield), enclosed document to F1-12-470 “Article Alain Jouffroy”, 19 March 1957, FLC F1.12.474.
- ¹⁸⁴ Le Corbusier, letter to Roberto Olivetti, 14 January 1964, FLC M2.8.104.
- ¹⁸⁵ Le Corbusier, letter to Roberto Olivetti, 14 January 1964, FLC M2.8.104.
- ¹⁸⁶ Jean Petit, Rho Olivetti, “Fragment de façade et coupe”, plate 38, 9 June 1964, FLC B129.

5 DISCUSSION

5.1 FROM THE ARTIFICIAL CLIMATES TO BIOCLIMATIC ARCHITECTURE?

The early hypothesis of this research stated that the collaboration of Le Corbusier with Missenard triggered a change of mind in the architect's approach to thermal comfort. As we argued, his first viewpoint, which was based on completely mechanized atmospheres, turned into an architecture that interacted with the local climate and the inhabitants' physiology. The latter angle, as we suggested, was close to the sphere of the subsequently named bioclimatic architecture. Even though this assumption also took into account the radical differences between modern architects' thinking and the recent implications of the architecture's ecological labelling (e.g., architecture as part of a greater ecological system, preserving natural resources or reducing energy consumption). Understanding this difference, a number of researchers have dealt with this premature "ecological" turn in Le Corbusier's work, namely: Abalos & Herreros (1987; 2000), Winter (1987), Fernandez-Galiano (1991), Sobin (1991; 2007), Almodovar Melendo (2004), Hawkes (2008; 2012), Dunnet (2008), Stein (2010) and Requena-Ruiz (2012b; 2011). According to this, other authors (Winter 1987; Torres Cueco 2004) suggested that the early "*Air exact*", with its mechanical logic, was almost dispelled from Le Corbusier's works in favour of a technical turn into a modern vernacularism from the mid-1930s.

In comparison with this approach, the present research provides a new argument that has emerged from the analysis of the documentary sources. Without being contrary to the previous, we state a more comprehensive interpretation placing Le Corbusier's works in broader social, technical and sensory arenas. In light of the results, we argue that Le Corbusier's approach to the construction of the architectural atmospheres, especially in its thermal part, stayed invariable in its fundamental guidelines from the late-1920s. It was, however, immensely enriched and better conducted through the experience of Missenard, resulting in another evolution of his *recherche patiente*.

An example that corroborates this hypothesis was the evolution of the *Air exact*. The thematic study of the FLC's documents, amongst which his notes on *L'Homme et le climat* reveal how Le Corbusier never abandoned the 1920s idea; furthermore, neither him nor Missenard refused a mechanical approach to climate control. In contrast, the contribution of Missenard led the architect to argue against the total insulation of buildings from the outdoor climate and also against heterogeneous thermal atmospheres. Thus, when he recalled the *Air exact* in the 1950s, it was not an air-conditioning system anymore, but a mechanical system that reacted to outdoor conditions in order to build indoor atmospheres adapted to programmatic conditions. What is more, late projects such as the Olivetti Calculation Centre, the Tokyo Western Art Museum or the Hospital of Venice implemented air-conditioning systems as a result of the programme, the climate and the local technology. The main difference between these works and those of the late-1920s was the implementation of a more complex understanding of the indoor thermal atmospheres, which he understood as a deep contribution for the *Homme Nouveau* utopia in the *Ville Radieuse*.

Understanding this viewpoint requires paying attention to the influence of Missenard in Le Corbusier's ideas about the environments for the *Homme Nouveau*. The current

report evidences how through Missenard's combination of physiology, technics and politics, the interpretation of the turn from the *isothermique* building into the bioclimatic one can also be interpreted as an architectural experimentation in the incipient Science of Artificial Climates.

Instead of passive or mechanical strategies, their main aim was to create an architectural interface between outdoor climate and human physiology. For both architect and engineer, low energy consuming resources or passive devices (as we call them nowadays) seemed to be a different array of strategies to achieve the same goal. The *aérateurs*, the so-called *transaération*, the ceiling-fans of Chandigarh, or the integration of greenery and water, did not attempt to avoid air-conditioning as an environmental conviction. They were, however, considered as a different range of strategies for achieving an architecture adapted to local climate and economy.

Summing up, with the interference of Missenard's Artificial Climates in the late-1930s, Le Corbusier's works became more complex in their understanding of the inhabitant's physiological reaction and outdoors climatic changes. His universal and isothermal building of the 1920s evolved into a responsive architecture that was closely related to these facts by equally using both mechanical and passive strategies. Consequently, the contextualization of this period of Le Corbusier in a vernacular or bioclimatic approach to thermal comfort is challenged by the results of this research. Hence, it has to be understood in parallel with the medical, social and industrial interests in the rise of Missenard's Science of the Artificial Climates.

5.2 AMBIANCE, ATMOSPHERE, CLIMATE

The relevance of the notion of milieu in the constitution of Modernism from the late-nineteenth century until the 1930s has been reported by several authors in medicine, cultural studies or industry (Canguilhem and Savage 2001; Gandolfo 2008; Feuerhahn 2009; Corbin 2014b). Throughout this research, it has been revealed how the notions of milieu, ambiance and climate were enhanced not only in the scientific and cultural arenas, but also in architecture. The study of modern architecture focusing on these notions involves turning around the ocularcentrist tradition of the discipline by widening the centre of attention to the sensory perception of architecture. This approach, which is at the core of this research, states that what we experience in architecture is a combination of transient effects, which modify our perception of the built environment rather than the built object itself.

When Le Corbusier argued in favour of an architecture designed from the interior in *Vers une architecture* (1923), he recalled the terms "*sensation architecturale*" and "*sensation sensorielle*", which according to Darò (2013, 99) supposed his early approach to the ambiances. As this research reveals, this angle was also expounded in the architect's notes on Missenard's *L'Homme et le climat*, where he wrote down terms like "*nature des matériaux (sensation)*", "*l'ambiance, la sensation*", "*la sensation de chaleur*". In particular, these type of notes demonstrate an interest in the inhabitant's relation with architecture that was not only vision-centred; therefore, the architect's thought seemed not to be coincident with the so-called hegemony of vision in modernity (Kleinberg-Levin 1993). As it has been reported, both architect and engineer considered the air properties perceptible for inhabitants through breathing, touch and smell but at the same time they were related to hygiene, health and comfort. Thus, the control of

temperature, humidity and air quality in architectural atmospheres became both an increasing demand of society and an ambition of engineers and industrialists.

The current understanding of the notion of ambiance cannot be mixed with the modernist' approach to milieu, ambiance and climate. The three of them are semantic and etymologically linked because they refer to what surrounds/envelops us, which also influences ourselves, however the nuances in the signification is relevant here. According to Nilsson-Ehle (1957), "milieu is a sober, neutral and strict term" that was related to some extent to its scientific tradition. Ambiance and climate, he argued, were more suggestive terms, linked to both affective and metaphorical dimensions respectively. As Thibaud (2012) argues, climate is a more neutral term that is related to its atmospheric definition and it only gets an affective connotation in a figurative sense. Indeed, ambiance also contains a moral or emotional character that gets a positive connotation.

These double moral and scientific meanings connote the choice of the term climate by Missenard and his contemporaries between the 1930s and the 1950s. In fact, the climate and its effects had received considerable attention throughout the first half of the twentieth century and it was dealt with by many other disciplines. The climate relation with geography was addressed by geographers such as Huntington in *Civilisation and Climate* (1924) or the German Albrecht Penck (1858-1945). On a governmental level, in 1937 the American Air Force Weather Service was founded, which was renamed in 1946 as the Air Weather Service and was directed from 1949 by the German climatologist Helmut Landsberg (1906-1985). In 1951, the United Nations settled the WMO World Meteorological Organization, which addressed a variety of big scale (climatic models) to small scale (climatic chambers) research. Also a sensory approach was concurrently suggested through the history of climate, which according to the sensory historian Alain Corbain (2014b) was original of the late-1950s and the early-1960s. This discipline, he argues, established a chronological cycle of meteorological history. Furthermore, it was not strange to hear the term climate related to the house, such as the work of the engineer Robert Leroux "*La climatologie de l'habitation*" (1946). Shortly, the interest of Missenard and Le Corbusier in climate that has been evidenced in this research was, furthermore, the reflection of the significance of the notion in this period. The contribution of both architect and engineer was the exploration of the development of indoor climates through architecture that were responsive with the exterior climate of every location.

Given that Modern Architecture's contribution to the construction of modern society and the *Homme Nouveau* was built upon biological, industrial, sociological and cultural viewpoints at the same time, the double connotation of the term climate made it even more pertinent. If Missenard argued in favour of a physiological, social and moral control through the control of indoor conditions, his Science of Artificial Climates and its materializations can therefore be understood in a broader framework, especially considering the political connotations of his scientific relationships.

A thematic lecture of the modern period focused on these artificial climates shows that it was a controversial issue for modern architects. In this sense, the work of Pallasmaa evidences an approach to a multi-sensory experience of architecture. Based on the history of art and the psychology of perception he argues that the works of

modern architects like Frank Lloyd Wright, Alvar Aalto, Louis Kahn and Carlo Scarpa can be given as examples of this approach (Pallasmaa 2010).

Without going into detail, Frank Lloyd Wright supported the fact that architecture, as a human envelop, should deal directly with the local climate rather than to create an ideal or false one. He trusted in the human body's thermoregulatory skills. In the chapter "Air conditioning?" of his book *The Natural House* he claimed, "I think it is far better to go with the natural climate than try to fix a special artificial climate of your own. Climate means something to man. It means something in relation to one's life in it" (Wright 1954, 176). Alvar Aalto paid special attention to heat and air condition control as part of a global approach to the haptic experience of architecture. The Finish architect studied the source of heat, the thermal qualities of the materials' surfaces, the method to transmit heat energy and how the inhabitant perceived it (Linnanmäki 2012). A way of conceiving architectural atmospheres that he extended to daylight, lighting and sound as well (Passe 2008).

The quest for the definition of home comfort established between the American journals *Arts & Architecture* and *House Beautiful* from the 1940s to the 1960s also dealt with this issue. If both of them tried to establish the new definition of the American house after WWII as a re-orientation of the war industry, their approaches to thermal comfort were opposite. *Arts & Architecture's Case Study Houses* (1945-1966) supported a non-air conditioned angle, which was linked to the modernist's aesthetics of big open spaces and new materials such as glass and steel (Entenza 1945). On the other hand, the *Pace Setter Houses* (1946-1965) were fully air-conditioned, recovering an aesthetic of smaller windows and American traditional atmospheres (Penick 2007). Thus, thermal comfort was fully integrated in the construction of the new American's house life identity; therefore it was part of two wider economical, industrial and social projects.

Even if conceptually far from the modernist paradigm, almost contemporary were the urban utopias that aspired for the reconstitution of an artificial nature inside of envelops with different scales. Mainly we can refer to the *Domes* of the American engineer Buckminster Fuller (patented in 1954), to the Dutch painter Constant Nieuwenhuis' project of *New Babylon* (1959-1974), to the *Ville Spatiale* of the French-Hungarian architect Yona Friedman (since 1958), or to the French artist Yves Klein's proposal for the *Air Architecture* and for the *Cité Climatisée* (1959-1961).

In brief, the collaborative work of Le Corbusier and Missenard on the architectural materialization of the artificial climates must be understood in its social, political, technical, scientific and sensory contexts. What is more, some of their colleagues worked in the same direction. The choice for the term Artificial Climate deliberately linked the architectural atmospheres with the control of the physic parameters of air (e.g., temperature, humidity, wind speed or air quality) on the one hand, with the construction of the Modernism's social and biological utopia on the other hand.

5.3 THE ARCHITECTURE OF THE PHYSIOLOGICAL CONTROL

The documentary sources studied here reveal the connection between Le Corbusier's works and the climatic determinism supported by Missenard. However, if Missenard's books were obviously related with this theory, we have only found direct references in a few of Le Corbusier's documents. Namely, the copy of Missenard's *L'Homme et le climat* owned by Le Corbusier full of notes that connected the engineer's work with the

theories of the *Ville Radieuse* and some personal letters regarding to the *Grille Climatique*. Apart from these, other links can only be traced through Missenard's writings and the variety of coincidences with the architect's texts.

As we have reported, several of the architect's texts, such as *La Maison des Hommes* or *Rétablir les conditions nature*, show ideas of thermal comfort and indoor atmospheres previously argued in Missenard's *L'Homme et le Climat*, *A la Recherche de l'Homme*, *Le Chauffage des Habitations* or *Vers un Homme Meilleur par la Science Expérimentale de l'Homme*. Although all of these works include just a few quotes between each other, Le Corbusier's approach to climate and thermal comfort as well as the interest in housing of Missenard to control human biology or daylight regulation. In other words, the understanding of architecture as a machine for physiological and climatic interaction was part of their common ideological background with the internal reports informing their viewpoint in works such as the *Grille Climatique* or the *Maison du Brésil* give evidence of it.

During the 1950s, the collaboration with Missenard did not only influence Le Corbusier. The chief architect of the *Atelier 35S*, André Wogenscky, was also especially permeable to the Artificial Climates thought. His subsequent writings and conferences of the late-1960s and 1970s assumed several of the engineer's ideas and enhanced architecture as a machine for building "artificial climates". His approach, nonetheless, aimed to provide inhabitants with the best air quality and comfort conditions inside, which was not coincident with Missenard purposes. In contrast, it seems paradoxical that a collaborator like Iannis Xenakis, who was completely involved in the development of the *Grille Climatique*, has not been revealed as a supporter of Missenard's contributions.

All this complexity, however, was part of a background that was not directly stated in the project reports, plans or sketches. As it has been stated, all these sorts of documents were focused on technical aspects. Moreover, except for the *Grille Climatique*, the projects were composed of descriptive and executive files, whose assertions and decisions must be contextualized in the general framework. Consequently, if they are studied out of their context, they are just regular documentary sources interesting only from the angle of the history of architecture.

This interest in the power of indoor atmospheres for controlling human thermoregulation system has to be placed in the broader context of the *Homme Nouveau* utopia. In particular, it is influenced by the Eugenic thought, which was part of a more general consciousness of certain intellectual elites. In this regard, Wikler (1999) and Cassata (2011) underline how Eugenics was "a movement for social betterment clothed in the mantle of modern science, claimed the allegiance of most genetic scientists and drew supporters from the political right, left and centre" (Wikler 1999). In fact, the biological and social betterment started by the conditioning of the inhabitant's way of life. This thinking was very disseminated at the period in all areas of life. The health enthusiast John Harvey Kellogg (1852-1943) detailed the normal itinerary of meals in the human body in his book *The Itinerary of a Breakfast* (1918)¹⁸⁷ and he subsequently founded his breakfast cereal company. Similarly, the doctor Philip Lovell advocated natural methods for healing and preventive health care based on exercise, heat and thermal cures, open-air sleeping, nude sunbathing and vegetarianism. This *modus*

vivendi was also related to modern architecture through the Lovell Health House (1927-29) designed by Richard Neutra in Los Angeles.

The faith of engineers, architects and designers in modern science's assumptions gave them a theoretical framework to inscribe their works in the common utopia of a newer and better society. Thus, all kind of products susceptible to establishing a relation with the human body were designed in order to contribute to this collective project. Cogdell (2004) reveals how American industrial designers of the 1930s adopted the ideas of the national concern for biological efficiency, which was built upon Eugenics theory. Well-known designers, she follows, were involved in this trend of streamline design, such as Egmont Arens, Norman Bel Geddes or Raymond Loewy (Cogdell 2006).

The total control of indoor air conditions seems to be just a step more in this evolution. The link between heating industrials and the incipient air-conditioning industry with the physiological and physical studies of indoor atmospheres shows the same type of links. As Ackermann (2002) reveals, the framework of the environmental or climatic determinism gave to this industries a strong backing that placed their contributions in this human project. Engineers, industrialist and physiologists worked together in the same way, turning indoor climate control into a main necessity of modern society.

In this report we have discussed how Le Corbusier and Missenard contributions must be understood surrounded by this entire context. The writings of both Le Corbusier and Missenard reveal that they were aware of these ideas. Their works, therefore, were not spatial or technical masterworks isolated, but contributions to the new social challenge. The ideological link of Modernism and Eugenics is nowadays argued by a number of authors (Turda 2010; López Durán 2009; Greene 2012). As Turda reports, Eugenics was "not only as a scientific narrative of biological, social and cultural renewal, but also as the emblematic expression of programmatic modernism" (Turda 2010, 2).

5.4 TECHNICS AND SPATIALITY OF THE ARTIFICIAL CLIMATES

Missenard's work has proven relevant during all the research to connect physiology and technics with the wider framework of the environmental determinism. Thus, his works became internationally influential for the construction of the notion of thermal comfort. This point has been corroborated by many historians and sociologists on thermal comfort (Ackermann 2002; Ryan 2012; Chappells and Shove 2004; Marino 2014). Built upon this base, Missenard's contributions to engineering have shown their importance in Le Corbusier's works, becoming even a heating techniques laboratory in some cases, such as the *Maison du Brésil* or the kindergarten of the *Unité d'habitation* in Firminy. Apart from his general contributions documented by Gallo (2014; 2006) and Marino (2014), his collaboration with Le Corbusier remained unclear. As this report has shown, both physiologically and technically Missenard's experiments converged in the works of Le Corbusier during the 1950s, changing his viewpoint for subsequent works.

In this report, we also analysed how Missenard and his colleagues of *Ets Quint Flammand* and *Ets Missenard Quint* tried to go beyond the logics of the technical installations of heating systems or air-conditioning. Like their advertisements in architectural journals have show, from the very beginning they looked for healthy environments that triggered biological betterment according to the Science of the Artificial Climates. Their patents and prototypes were, consequently, in line with this

aim. In this sense, Missenard argued in favour of the heated-slab system. In particular, he developed a patent that was adopted for all his collaborations with Le Corbusier, making the architect leave his early obsession with the homogenous atmospheres of the air-blowing systems to one side. The archive works of this research have revealed new documents detailing the patent through drawings and texts but also explaining its adaptation to each one of Le Corbusier's works.

Missenard's heated-slab system, which was progressively implemented in Le Corbusier architecture, was more than a typical modern translation of the hypocaust (Marino 2014, 407), which appeared in an array of modern buildings like the *Ecole de Plein Air* of Eugène Beaudouin and Marcel Lods (Suresnes, 1935), the *Openluchtschool* of Johannes Dui (Amsterdam, 1930), the *Viipuri Library* of Alvar Aalto (Vyborg, 1935), or the *Highpoint apartments* of Berthol Lubetkin (London, 1938). The documents studied here reveal that for Missenard the heated-slab was just the more optimal way (for health and comfort) for transferring heat, nonetheless, it was just a part of a more complex system.

First of all, the conception of Missenard's heating system started by adapting the heat production to the gains and losses prevision of the building. Different orientations were heated to different temperatures according to the sunlight gains and thermal losses. For instance, the *Unité d'habitation* in Rezé or the *Maison du Brésil* were provided with different systems for the public ground floor, the residential first floor and last floor, as well as the East, West and South apartments. Secondly, indoor temperature was regulated according to the outside temperature, producing variable thermal atmospheres that connected indoors with outdoors. As previously explained, the *Ets Missenard-Quint* developed a special thermal sensor for this aim. Thirdly, each space was heated up to a different temperature according to its function and its place in the thermal transition inside-outside. All this richness in thermal atmospheres was non-existent in the works of Le Corbusier with the *Air exact* or the radiator systems, where he rather promoted homogenous environments for all kinds of buildings. This different approach can be explained by Missenard's physiological approach in his more theoretical books.

During the 1920s and early-1930s, the radiators constituted the main heating system for housing integrated in Le Corbusier's works. As Nam (2012) revealed, it was not just a technical element, but the radiator was part of a *mise-en-scène* that was equivalent to his pictorial compositions. In the same period, the *Mur neutralisant* that accompanied the *Air exact*, enhanced the architectural valour of the façade becoming a complex element of the project that was capable of insulating thermally and acoustically, heating and cooling, providing sunlight accessibility and creating the modern and functional aesthetic of the building (Gallo and Fernandez 2010; Urbano-Gutiérrez 2012).

This report discusses how all these elements were replaced in the 1950s at Le Corbusier's imaginary by the floor, which became a central issue for the projects and the construction. On the one hand, the drawings insistently represented the floor in the plans, details and sections for the structure, the heating and the partitioning, not only in its technical matters but also in the flooring distribution and the surfaces colours. On the other hand, the documents proving the evolution of the buildings works continuously dealt with the floor characteristics and details. Several documents give evidence of it, such as: the coils distribution issues; the heated-slab tests; and the choice

of flooring materials between *Bulgomme*, *Viniflex*, *Dalami*, concrete paving or black slate sheets.

The floor was not only important from an aesthetic viewpoint but also in a sensory approach to the architectural atmosphere. Only environmental techniques like the radiant heating system favoured building complex spaces like the ground floor hall of the *Maison du Brésil*, with its curved walls and glazing, which changed the conventional interior-exterior definition. In this case, the exquisite composition of the flooring in parallel strips of black slate sheets contributes to the thermal atmosphere of the place and at the same time gives visual relevance to the thermal source.

In a more general way, Missenard's contributions such as the heated-slab or the *aérateurs* came to enhance the *Open-plan* in the architecture of Le Corbusier. For the former, the engineer's documents claimed several times that in order to obtain a better performance, the surface exposed to the inhabitants' bodies should be as big as possible. For the latter, the logic of cross-ventilation imposed open-plans that connected opposite façades in order to improve the breeze movement. It was evidenced in the sketched of the *Grille Climatique* and all the Indian projects, but also in the ground floor of the *Maison du Brésil* and its troubles with cross-ventilation on the residential floors.

Finally, the archival sources about Missenard's collaboration in thermal comfort reveal that the *Air Exact* never disappeared from his mind and, moreover, it was improved for his very last works. This evolution, which seems influenced by Missenard's approach to thermal comfort, shared its role with a variety of systems, such as cooling garden roofs, heating floor systems, fan ventilation or *aérateurs* cross-ventilation. The documents prove that each one of these systems was deeply connected with a different spatial and functional approach to architecture, which was aimed at developing atmospheres adapted to the architecture of every case.

NOTES:

¹⁸⁷ In fact, the book was fully entitled *The Itinerary of a Breakfast: A popular Account of the Travels of a Breakfast through the Food Tube and of the Ten Gates and Several Stations through Which It Passes, Also of the Obstacles Which It Sometimes Meets* (1918).

6 CONCLUSIONS

This report has focused on how the concomitant thoughts of Le Corbusier and André Misenard explored the power of the built environment as a key arena for the environmental conditioning at the service of the Modernist utopia. As we have argued, the total control of the living atmospheres that they enhanced was an architectural consequence of what other fields were exploring at the same time. It is therefore clear that neither Le Corbusier nor Misenard were alone supporting this angle, given that the promise of science for a human betterment was disseminated in many other contexts and countries. Their contributions, however, have revealed the value of constructing an experimental approach that consciously connects physiology, climatology, techniques and architecture to build the ideal atmospheres for modern society.

Adapting to the field of architecture, Schorske's assertion in *Thinking with History* (Schorske 1998), we have argued that architectural research should tamper with the mythology of the autonomy of the architectural knowledge and its milestones prevailing in the architectural guild. To do so, this research has been developed in three main steps that enhance scientific, social and ideological contexts, as well as the contributions of the collaborators of Le Corbusier. Firstly, it reconstructs Misenard's professional and ideological backgrounds according to the greater framework of both the scientific and engineering communities of Europe and America. Secondly, it traces the various exchanges between Misenard and Le Corbusier through shared and individual documents. Lastly, it unveils the works that materialized their collaboration, establishing a thematic reading of them.

All the three phases have revealed a number of personal links and documentary sources (e.g., letters, advertisements, pictures, plans, postcards, patents, meteorological narrations, or sketches) that connect the history of architecture with the history of techniques and the history of sensory. This multidisciplinary use of the sources has also been enhanced for the bibliographic study, adopting references coming from the history of architecture, the history of heating and air-conditioning, the theory of perception, the history of medicine, architectural theory or building physics.

Since the nineteenth century, the housing environment has been the origin of various discussions focused on hygiene and health. As seen in Chapter 2.1, this hygienic way of looking at the home evolved in the late-nineteenth century to a more comprehensive angle, where the ambiance of housing stopped being considered as a source of problems to progressively become the core of the new society. Medical discovery and the industrial re-orientation after WWI inspired the incipient air-conditioning industry and the physiological research in order to launch their scientific and technological contributions for modern society. The ambition of controlling human environments to avoid "human decay", which was theoretically produced by the exposure to extreme climates, triggered in the rise of the environmental determinism theory between some elites. As examined in Chapter 0, this point also connected with the development of occupational medicine, which also studied the environment from the point of view of the physiological and psychological performance.

Placing this research in a wider framework, the contribution of Eugenics to the ideological context of Europe and America have been defined by various researchers as diverse ideologically (Turda 2010; Ackermann 2002; Cogdell 2006), because it was

spread geographically and adhered to by professional and political elites across Europe and America. The environmental determinism, as we discussed in Chapter 0, is one of the complex set of theories that were based on the social and cultural translation of Evolutionism. According to Turda (2010, 119), Modernism and Eugenics should be treated together as both have been intrinsic parts of modern European history. As seen in Chapter 3.1, both theoretical and experimental works of Missenard cannot be understood out of this context. Evidence of the relevance of this works were his connections with researchers from France, England, Italy, Germany or the United States, as well as the recognition that he deserved from the scientific community together with the architects and engineers community.

Missenard's thought about environmental determinism, thermal comfort and environmental conditioning systems suffered a progressive evolution from his first book-manifesto *L'Homme et le climat* (1937) to his last *Vers un homme meilleur par la science expérimentale de l'homme* (1968). As stated in Chapter 3.2, once he developed the Science of Artificial Climates, his works were mostly oriented to the reinforcement of the theory from different angles. It was also connected with his work as an industrialist; thus, he did not resign himself to propose technical installations (e.g., air-conditioning, heated-slabs, ventilation systems, or radiant panels) to be implemented in buildings. Paraphrasing Missenard, he aimed to place human beings in the most suitable conditions for their health and their activities, in short, to soothe them in the original and unadulterated sense of comfort. Indeed, he advocated for the environmental education of the human body to overcome its shortcomings resulting from biological conditions (e.g., life expectancy, fertility rate or work performance); therefore, his approach to indoor environments led to understanding as an entire therapeutic ambiance.

Though the implications of the Science of Artificial Climates were broader, its translation to an architectural point of view can be characterized by three global strategies. Firstly, indoor climates had to be similar to the natural conditions where the human body was shaped, isolating biological needs from cultural ones. Like the engineer said, "for the great majority of human beings acclimated to their habitat, the most rational solution, although seemingly paradoxical, would be to change their natural climate the least possible" (Missenard 1937). Secondly, the artificial climate should be connected with the outdoors climate and change with it all day through; then, they would preserve the thermal perception of living outdoors but with more optimal conditions. For achieving this aim, Missenard developed two parallel strategies: installing a thermal sensor of outdoor temperature to regulate indoor temperature; and introducing transitional spaces in the buildings with different temperatures, which became crucial to avoid strong thermal changes between inside and outside. Lastly, he encouraged the idea of creating heterogeneous indoor atmospheres, conceiving the building as an entire thermal landscape. According to him, each space had to be adapted to particular conditions of temperature, humidity and air movement depending on the role of the space in the system and its use. In this way, the inhabitants would be continuously exposed to controlled thermal contrasts as a sort of thermo-regulation training procedure, which would invigorate the human body and mind making them more resistant and efficient.

Even if Missenard introduced the theoretical context of environmental determinism to Le Corbusier, the architect was not unaware of it. As analysed in Chapter 4.1, before meeting Missenard he was in touch with theories built upon the same background through his personal and professional relation with Pierre Winter. He also approached these theories in his epistolary and personal discussions with the influential physician Alexis Carrel and his collaborator François de Pierrefeu. The archive research has also revealed that he owned a copy of Missenard's *L'Homme et le climat* in his personal library. It contains numerous personal notes that connect the engineer's thought with the *Ville Radieuse*, the *Air exact*, or many others of his concepts. The general influence of this idea is evidenced in subsequent works such as *La Maison des Hommes* (1942) or *Rétablir les Conditions Nature* (1957).

The previous assertion does not mean that Le Corbusier directly supported environmental determinism. However, he was surrounded by prominent ideologists of this sort of theories that nourished his thought, leading him to explore a personal architectural exploration. If Missenard clearly stood for a rigorous viewpoint of the environmental determinism theories applied in physiology and engineering, Le Corbusier was not clear on this point. He assumed the theories and methods of the engineer regarding thermal comfort, he learnt about heating and ventilation techniques, as well as understanding the role of them for the modern utopia. As discussed in Chapter 4.1, it seems clear that they did not agree until the very last consequences. On the one hand, for Missenard, Le Corbusier's approach created for the inhabitants the illusion of being in contact with nature instead of pushing the inhabitant outside, which would be a real contact with nature. On the other hand, for Le Corbusier, the engineer's assertions about the moral and behavioural control of inhabitants through architecture seemed to be too strong and not justified enough.

All this conceptual construction was also explored during their professional cooperation between 1951 and 1965; furthermore, it represented the link between their theoretical and professional frameworks expressed through the collaborators and employees of both offices. As examined in Chapter 4.2, it started with a project consultancy for the *Grille Climatique*, which was followed by five complete works: *Maisons Jaoul*, *Unité d'Habitation Rezé-les-Nantes*, *Maison du Brésil*, *Unité d'habitation Briey-en-forêt* and *Unité d'habitation Firminy-Vert*. During this association Le Corbusier evolved his attention to the climate on two lines. On the one hand, he focused on developing a more complex approach to the relationship of his architecture with the climate. Sunlight, rain, breezes, winds, humidity, heat radiation or vegetation became common elements to study in his projects once they worked together in India. On the other hand, Missenard's viewpoint on the artificial climates changed the architect's mind on his previous isothermal way to deal with architectural atmospheres. Thermal heterogeneity, radiant systems, cross-ventilation, or multiple comfort strategies became new elements to his projects. At the end of Chapter 4.2, the research also revealed three projects where *Ets Missenard-Quint* did not contribute directly, but its director's thinking can be indirectly traced to Le Corbusier consciousness on thermal environments. Namely, these works are the *Couvent de la Tourette*, the *Musée national de l'art occidental Tokyo* and the *Centre de calculs électroniques Olivetti*.

An array of different techniques integrated in architecture represented their approach to thermal comfort. Namely: the heated-slab system, *aérateurs* cross-

ventilation, vegetation humidity regulation, cooling and insulating garden roofs, fan ventilation, concrete heating panels, convector-radiators networks and air-blowing heating. From the beginning of their collaboration onwards, the adoption of the different techniques for environmental control became richer and more complex in Le Corbusier's works; therefore, each system was applied according to the conditions of each project.

Perhaps the clearest illustration of the fusion of Missenard and Le Corbusier's thoughts to experiment on architectural atmospheres has come through the discussion in Chapter 5. Four main discursive lines have been explored that connect the wider cultural, ideological and technical arenas with the particular details obtained at the archive research. Firstly, we have discussed the adoption of the premature bioclimatic approach of both architect and engineer in the 1950s, which finally seems to be a continuous evolution of the aspiration for a completely controlled environment related with the *machine à habiter*. Indeed, the same reasoning appears throughout Le Corbusier's work, evolving in a better and more developed understanding of thermal comfort, environmental techniques and architectural space.

Secondly, the use of the notions of milieu, ambiance, environment and climate has been analysed throughout the writings and projects, concluding that each one of them was used in a different way. In particular, the adoption of the term climate for the Science of Artificial Climates was related with its double neutral and moral meanings, also related with the origin of Missenard's theories. Moreover, the idea of creating indoor climates also involved a lively conception of architectural atmospheres, which were understood in a more homogenous way by other modern architects. Thirdly, the research corroborates that both the architect's and the engineer's ambition was to induce a physiological control through architectural atmospheres. The varieties of strategies reported are just evidence of the different experimentations to achieve this goal. Lastly, physiology and climate were connected with architecture by the technical innovations of Missenard. Le Corbusier's technical and spatial conception evolved to a different understanding of the role of weatherizing techniques and their aims; therefore, they connected with the modern notion of space, taking advantage of it to improve system's performance and to control inhabitants' reactions and perceptions.

In this sense, contextualizing how both architect and engineer dealt with the notions of climate and ambiance, as well as to study how these notions were a part of their thought and praxis, has been an essential point of this research. As discussed, both approaches were at the core of their collaborative work and it cannot be judged without this context. The thematic lecture stated here shows that the documents found at the FLC's archive have to be analysed understanding the main relevance of ambiances and climates in a wider framework, followed by the scientific and cultural elites' closeness to environmental determinism.

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