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23 Lucius Burckhardt, "Das Vivarium des Zoologischen Gartens Basel, vollendet 1972," *Werk* 59 (1972), 171-3.
 24 Christina May, "Landscape Habitat Immersion. Die Konstruktion immersiver Zoolandschaften im Kontext des US-amerikanischen Environmentalism," in Institut

für immersive Medien (ed.) *Atmosphären: Gestimmte Räume und sinnliche Wahrnehmung* (Marburg: Schüren 2013), 27-56.
 25 For example, see Ian McHarg, *Design with Nature* (Garden City, NY: Natural History Books 1969).

4.1.4 Experiments on Thermal Comfort and Modern Architecture: The Contributions of André Missenard and Le Corbusier

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ABSTRACT

The early scientific researches into the thermo-regulative response of the human body during the 1920s and the 1930s normalized thermal conditions in working and educational environments to improve user's performance. The European and American contexts of housing promotion and industrial development during post-war extended this approach to different environments.

Geographers, physiologists and engineers encouraged manufactured indoor atmospheres that could overcome human shortcomings resulting from environmental and biological conditions. Climate, indoor atmospheres and human body were interlinked to develop the ideal environment for modern society. Paradoxically, these original notions and researches have been used to promote both bioclimatic and weatherized architectures along the second half of the twentieth century.

The French engineer, researcher and industrialist André Missenard was a prominent contributor to the study on the thermo-physiology of comfort as well as its experimental application to engineering and architecture. As a collaborator of the architect Le Corbusier, his influence not only attempted technical fields, but to the whole notion of the ideal environment for modern society. Consequently, Le Corbusier's works during the post-war became a collective laboratory on hygro-thermal control, where passive and active systems were constructs of what Missenard called 'artificial climates'.

Based on an original research at the Foundation Le Corbusier archives and the French National Library, this communication presents the design method of the Grille Climatique and the buildings for the Millowners Association (Ahmadabad, India) and the House of Brazil (Paris, France) as study cases. As a result, the paper discusses the influence of physiology and environmental technology in the early approaches to thermal environ-

ments in architecture, what afterwards supported both bioclimatic and mechanical viewpoints.

KEYWORDS

Architectural atmospheres, comfort, temperature, Modernism, Le Corbusier, Missenard

THE EMERGENCE OF THERMAL COMFORT

The development of microbiology in the 1870s generalizes hygienistic precepts which link living environments and human body. The scientists' preoccupation with microbes is the origin of a new range of environmental prescriptions for urban and building design. Sunlighting and pure atmospheres become determining factors in the creation of the *Homme Nouveau* and lead an avant-garde architecture that, based on Hippocratic hygiene laws, develops a whole way of life to heal illness and to preserve society's health. More than a landmark, microbe discovery and hygienism are examples of the interest in the concept of milieu in science and culture at that time.¹

Generally speaking, two scientific approaches are derived from this notion during the first half of the twentieth century: the study of the human body's thermo-regulative response to the environment and the rationalization of human atmospheres to create perfect environmental conditions. Both of them interlink climate, indoor atmospheres and human body involving a wide range of professionals, such as physiologists, physicists, industrialists, geographers and architects.

The opinion of architectural practitioners converges regarding the hygienic, health-promoting and regenerative powers of certain types of architectural structures and environmental systems. Therefore, this promise of a perfect future, designed for the *Homme Nouveau*, makes some of the goals of modern architects permeable with those from racial science and eugenics. As historians like Turda² or Cassata³ note, this set of practices and scientific beliefs coincide around the common point of the biological improvement of the body.

ANDRÉ MISSENARD AND THE ARTIFICIAL CLIMATES

In this context, the French engineer and industrialist André Missenard (1901-89) develops his particular approach built upon climatic determinism theories, which link climatic conditions and human behaviour in both a biological and moral sense. In contrast to other engineers, he is critical towards the gradual rising of indoor temperature and the thermal homogeneity created by the conditioning systems, which he considers based on a false approach to thermal comfort. Thus, for Missenard, the aim should be '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'.⁴

Following this idea he proposes to join together 'all these concerns, and the realisation of the desirable atmospheric and calorific conditions for the human body, constituting a technique'⁵ that is different to the mere heating, ventila-

tion or air-conditioning of indoor spaces. He names it the *Science des climats artificiels*,⁶ based on the idea of building artificial climates that create optimal conditions for human life according to a purely physiological angle. Besides, these atmospheres should stimulate a biological reaction that invigorates the human body and mind making them more resistant and efficient.

Missenard's purposes are not focused on sick people anymore but on the whole of society. Consequently, he suggests that 'for the great majority of human beings acclimatised to their habitat, the most rational solution, although seemingly paradoxical, would be to change their natural climate the least possible'.⁷ Accepting the cultural deformation of thermal comfort to achieve the best working and intellectual performance, his proposal is based on colder environments that evolve in their temperature according to the outside variations. The human body, he says, must be continuously exposed to controlled thermal contrasts as a sort of 'thermo-regulation training' procedure, but these variations cannot be higher than 8° C8. Thus, the role of transitional spaces becomes crucial for the thermal experience of architecture.

Books like *L'homme et le climat* or *A la recherche de l'homme* give evidence that his aims are much broader than providing thermal comfort, displaying hygienic rules or installing heating systems. Missenard advocates the environmental education of the human body to overcome its shortcomings resulting from biological conditions (i.e. life expectancy, fertility rate or work performance).⁹ Consequently, his approach to architecture leads to an understanding of the built environment like an entire therapeutic ambiance.

The book *L'homme et le climat (1937)*, reflects, for the first time, on a panorama of his ideas. Due to the influence of Missenard on the collective of architects, it is of no surprise that Le Corbusier (1887-1965) owns a copy of the book where he writes down copious comments¹⁰ that link Missenard's theories with his concerns about built environments. In particular, his notes appear to look for scientific support for his global project of the modern city, the *Ville Radieuse*. Hence, his annotations focus on sunlight, ventilation, health or physical activity, which are also compiled in a parallel index of the book.¹¹

Vice versa, personal letters show the relevance that Missenard gives to his meetings with Le Corbusier and Alexis Carrel at the *Fondation Française pour l'Etude des Problèmes Humaines* as well as to Le Corbusier's theories and works. He seems to admire the master 'I have met few architects as concerned about these issues [thermal matters on architecture] as Le Corbusier',¹² even if they do not always agree 'it is worrying that the large bays of Le Corbusier, 'incorporating landscape in housing', give the dangerous illusion of an open air life'.¹³

AN ENVIRONMENTAL METHOD: CLIMATIC GRID AND MILLOWNERS ASSOCIATION BUILDING

After coming back from Chandigarh in November 1951, Le Corbusier writes to Missenard asking for his advice due to the challenge that this big commission entails in a different climate.¹⁴ The letter expresses his intention of developing a method to generate works that can operate in any particular set of climatic conditions. Besides, the architect reveals the wider aim of exploring new ways to deploy other procedures for regulating the architectural environments. In Le Corbusier's words, 'the regulations concerning this new capital imply decision-making in terms of hygiene laws (of any nature other than our conformist regulations that had resulted from all the agreements)'.¹⁵

In a really intensive process of several letters and meetings they establish, with the aid of Iannis Xenakis (1922-2001), the *Programme d'études des Conditions Climatiques Optima et des Moyens Architecturaux de correction*.¹⁶ Xenakis specifies four variables for the 'climatic ambiance' (temperature, relative humidity, wind velocity and temperature of walls) in order to determine 'the optimal and theoretical variations of the environment, to conserve or to increase the "rendement VITAL", by considering variations over days and seasons'.¹⁷

The different names of the grid during the process also give evidence of the influence of Missenard on the atelier's thought. On 20 December 1951, Xenakis draws a grid called *Grille d'hygiène climatique*,¹⁸ but the term hygiene is removed afterwards.¹⁹ At the same time, Samper's drawing of the Secretariat testing the grid criteria is called *Esquisse générale de la grille pour le conditionnement climatique du Secrétariat*.²⁰ The final chart is drawn up in a document dated 31 January 1952,²¹ where it is finally named *Grille climatique*. It is defined as

a material way of visualization allowing to enumerate, coordinate and analyse climate data from a defined location (latitude) in order to guide architectural research towards solutions related to human biology. It is necessary to regulate and to effectively correct the excesses of excessive climates and



Figure 1. Climatic grid based on Chandigarh's climate (FLC5623). Source: © Fondation Le Corbusier-ADAGP

to create, through architectural devices, the conditions capable of ensuring well-being and comfort.²²

In the chart, three titles are placed along the horizontal axis, which are changed afterwards when the chart is applied to the project of the 110 mq Houses. The first, *Conditions d'ambiance* (later *Données climatiques*) is composed of the original four factors: air temperature, relative humidity, direction and velocity of winds and sunlight and thermal radiation of constructions.

The second column is entitled *Corrections en vue du confort et du bien-être* (later *Corrections à apporter*), which replaces that of *conditions optime* and the search for the *meilleur rendement vital* of the first version. The information is supposed to be fulfilled by a '*physico-biologiste*'²³, which seems to be the real program that triggers the architect's intervention.

The third column bears the title *Architectural solutions* (later *Procédés architecturaux*) and signals, by the presence of a stamp with the letter D (for drawing) and a numeric code, the existence of a solution duly studied. The sixteen explanatory diagrams refer to different environmental solutions which are personally signed by Le Corbusier.²⁴

After this prolific period, the *Grille Climatique* disappears from the works of the atelier. Even if Le Corbusier supports it: 'In Chandigarh, this *Grille Climatique* has not been taken into account and I regret it bitterly [...] although this grid has been lost, I am ready, if I am asked, to draft a new one'.²⁵

Nevertheless, all the studies and strategies are prominent in the background of the architects when they are designing either the Indian projects or the previous projects. This is the case of the Millowners Association building (Ahmedabad, 1956), in project phase from 1951 to 1953, whose materialization is directly influenced by the grid strategies. This is evidenced by comparing the early proposal of Doshi in March 1952, which only responds to programmatic issues with an almost purist shape, and the plans of the second proposal on October 1952.²⁶

The first environmental control device, as usual in Le Corbusier's works after the 1940s, is a façade materialised by a reinforced concrete *brise-soleil*.²⁷ Both the East and West orientations have their walls closely conditioned by the solar path angles.²⁸ The East-side's blades are 1.10 m deep and they are open to the sunlight, the breeze and the panorama of the river. On the contrary, the West-facing blades are 2.00 m deep and they are given a diagonal orientation of 45°, which prevents the exposure to direct sunlight and noise. In Le Corbusier's words 'the building is open to the winds. The East and West facades have their *brise-soleil* calculated according to the latitude of Ahmedabad'.²⁹

The building is open to the passage of air, leaving the private areas en-

closed with specific walls adapted to their particular conditions. When the enclosures are East or West-facing, they regulate the exposure to sunlight through windows with curtains as well as air circulation with the *aérateurs* placed every 1.42 m.

The location in opposed walls and the narrow proportion of *aérateurs* ensure cross-ventilation for air renewal and heat dissipation of the spaces, a point that Le Corbusier and Missenard consider essential in achieving the ideal atmospheres. Paradoxically, the high clear-height (3.66 m) of the spaces, typical of both Indian and Mediterranean vernacular architecture to mitigate the heat effect, is argued by the architect as only requiring the installation of ceiling-fans, which replace the expensive air-conditioning system.³⁰

Other strategies of the grid are applied. Firstly, vegetation is incorporated in jardinières integrated in the *brise-soleil* in order to reduce sunlight gaining the slabs on the one hand, as well as to collaborate in the evaporative cooling on the other. Last of all, thermal stability is accomplished by using both garden and pond roofs, as well as by North and South blind brick walls of high thermal inertia.

ARTIFICIAL CLIMATES IN ACTION: THE *MAISON DU BRÉSIL*

The entire set of environmental methods and techniques that Missenard deploys during the 1950s is supported by his studies of the physiological reactions of the human body to thermal environments. In particular, during the 1930s, he pays special attention to: the effect of wall temperature on thermal comfort, which leads to the resultant temperature graph (1930) and thermometer (1934); the evaporation heat loss of the human body and the consequences of dust, ionisation and magnetic fields on air quality. As a result of his research, he suggests 18-19° C dry-bulb temperature and 50% relative humidity for healthy people in relaxed conditions, which means a resultant temperature of 16-17° C, as well as a low air velocity in order not to mix dust bacteria with the breathable air.³¹

As the head of Ets Missenard-Quint he uses the know-how in central heating systems of the company to promote thermally active surfaces as a modern way to develop artificial climates. These procedures combine perfectly with the qualities that he promotes for the ideal environments, but also with the spatial ones of modern architecture.

For developing their installations, Ets Missenard-Quint makes use of Missenard's patent for a radiant floor heating system that integrates heating pipes in the concrete slab. However, they also have the right to work with the patent of the English company Richard Crittall & Co.,³² which is at the same time licensed to use Missenard's patent out of France. It is also a

hydronic system of radiant panel-heating installed inside the surface layer of ceilings and walls. Both patents are proposed for the projects of the company but paying attention to the difference between them: 'the extension of the term "radiant heating system" [...] was applied to the ceiling heating systems, whose calorific emission consisted mainly in radiation, as it was preserved when the heating surfaces became a vertical wall, even the floor whose transmission by convection is pretty much equal to the one by radiation'.³³ Nevertheless, Missenard's patent appears to be less expensive and is the only one that they installed for Le Corbusier's works.

In the case of the *Maison du Brésil* (Paris, 1953-9), the collaboration follows the previous working experiments for the *Maisons Jaoul* (Neuilly-sur-Seine, 1951-5) and the *Unité d'habitation* (Rezé, 1949-56), where the issue of thermal comfort is dealt by applying Missenard's patent. However, what seems to be a mere continuation of previous works³⁴ for them becomes a clue to understanding their partnership.

For this project, Missenard's team proposes a scheme based on two heating techniques. Firstly, for most of the spaces of the building they preview a heated slab system to produce the base temperature for all the building except for the theatre, where an air-heating system is proposed. Air-convectors complement this system in spaces that have particular requirements, mainly partitioned rooms on the ground floor as well as the first and last floors.³⁵

The project description and the plans of Ets Missenard-Quint seem to reflect a more complex approach to the heating system, becoming a basic materialization of Missenard's theory of thermo-regulation training.³⁶ At first, the rooms and common spaces of the private floors are only heated up to 18° C, but the corridors are not heated, which leads to a lower temperature for the transition spaces.³⁷ Then, the ground floor temperature is designed to have a mean temperature of 15° C for the hall and the small entry box, which constitutes the threshold inside-outside, is not heated. Last of all, the theatre is heated up to 18° C but with an air heating system that allows intermittent use.³⁸

All this richness in thermal atmospheres does not seem to be evidenced in previous Le Corbusier's projects. Moreover, with proposals like the air-exact in the late 1920s, he rather promotes homogenous environments for all kind of buildings. The new viewpoint is explained by Missenard's physiological approach in his more theoretical books.

It is also interesting to note the relevance that flooring materials take at this point. They are not only important from an aesthetic viewpoint but more in a sensory approach to the space. Only environmental techniques like the radiant heating system allow for the building of complex spaces like the ground



Figure 2. *Maison du Brésil* in wintertime. Source: Ignacio Requena Ruiz, 2010.

floor hall, with its curved walls and glazing that changes the conventional interior-exterior definition.³⁹ As a result, 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.

For the ventilation and heat dissipation in summertime, the architects conceive two strategies based on their Indian experience. The ground floor is equipped with eight *aérateurs*, whose positions in the *pan-de-verre* façades are apparently chosen to favour cross-ventilation, especially all along the main hall. Nonetheless, the rooms have one *aérateur* in the façade, which is the air circulation vent, and a second *aérateur* that connects with a vertical air-duct up to the roof chimney rigged with a fan.⁴⁰ This scheme, which was previously developed at the Secretariat of Chandigarh, is imposed by the disagreement of the *Cité Universitaire* with the cross-ventilation running through common spaces, corridors and kitchens because of the fire risk.

As in other housing works of that period, the loggia *brise-soleil* is almost an axiom to regulate the temperature and day-lighting of the indoor atmo-

sphere in summer and winter, as well as an in-between space that expands the possibilities of the space.

CONCLUSIONS

The current paper presents, how Missenard's approach to living atmospheres and environmental determinism can be traced in Le Corbusier's late works. The two study cases presented are examples of the influence in modern architecture of the early development of the notion of thermal comfort and the integration of environmental techniques in the architectural design.

In my opinion, these study cases show modern architecture as a the carrier that disseminates a common scientific and political positioning on the thermal qualities of the living environments for the *Homme Nouveau*. This paper throws light on how the collaborative work of Missenard and Le Corbusier can be representative of this process.

As the research reveals, neither for Le Corbusier nor for Missenard appear to be differences in applying passive or weatherising strategies to develop indoor atmospheres. For them, both procedures aim to create artificial climates and can be adapted to the climatic and economic conditions of each location.

Finally, the archival evidences reveal that the main environmental idea lying behind their work is to re-place inhabitants in their natural conditions, which they support as the best to developing their biological capacities. Even having similarities to the current environmental approach in the use of passive strategies and thermal comfort, Le Corbusier and Missenard's work focuses on the biological improvement of the human body rather than in the thermodynamic efficiency of buildings or systems.

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1 For example, in the French context, the physiologist Claude Bernard (1813-78) or the writer Emile Zola (1840-1902).

2 Marius Turda, *Modernism and Eugenics* (Hampshire: Palgrave Macmillan, 2010).

3 Francesco Cassata and Erin O'Loughlin, *Building the New Man. Eugenics, Racial Science and Genetics in the Twentieth-Century Italy* (New York: Central European University Press, 2011).

4 FNB - Fédération Nationale du Bâtiment, *Hommage au Président Félix André Missenard: En l'honneur de son élection à l'Académie des Sciences* (Paris: Sedit, 1976), 17.

5 André Missenard, "Le Conditionnement des Locaux. Conceptions et Réalisations Modernes," *La Technique Moderne* 7 (1934), 1.

6 The first time he proposed this term was in André Missenard, *L'Homme et Le Climat* (Paris: Librairie Plon, 1937).

7 Ibidem, 233.

8 André Missenard, "Le chauffage des habitations du point de vue physiologique et hygiénique," *La Presse Médicale* 81 (1938), 16.

9 This idea was inscribed in a global eugenicist thought that believed that education, selection and environmental conditioning will improve our specie.

10 Le Corbusier's personal copy of the book is preserved at the archives of the Fondation Le Corbusier (hereafter FLC), where I could study completely.

11 Le Corbusier's personal copy of the book

is still preserved at the archives of the FLC.
12 André Missenard, "Hommage à Le Corbusier," *Industries Thermiques et Aérauliques* (1966), 72.

13 André Missenard, *A la Recherche de l'Homme, Evolution* (Paris: Librairie Istra, 1954), 2.

14 He is so aware of the importance of climate for the Indian projects that during the trip in November 1951 he gathers information on the Indian climate by meeting with Jehangir Ratanji Dabadhoy and Homir Jehangir Bhaba, founder and physicist of the Institute of Fundamental Research of Bombay. Cf. Le Corbusier, letter to Pran Nath Thapar, 9 December 1951, FLC P2-17-183.

15 Le Corbusier, letter to André Missenard, 3 December 1951, FLC, E2.16.14.

16 Xenakis, "Programme d'études des Conditions Climatiques Optima et des Moyens Architecturaux de correction," 16 December 1951, FLC, P2.1.1.

17 Daniel Siret, "Grille Climatique, 1951," in *Le Corbusier Plans*, vol. 11 (Paris: Echelle-1 y Fondation Le Corbusier, 2005).

18 Le Corbusier, letter to Jane Drew, 20 December 1951, FLC, G2.11.26.

19 Le Corbusier, letter to Jane Drew, 21 December 1951, FLC, P2.1.9.

20 Samper, "Esquisse générale de la grille pour le conditionnement climatique du Secrétariat," 21 December 1951, FLC2642.

21 Atelier Le Corbusier (hereafter FLC), "Grille climatique," 31 January 1952, FLC P2.1.3.

22 FLC, P2.1.3.

23 For the first attempt, Missenard draws up the notes personally. Cf. Missenard, "Corrections désirables dans les locaux," 16 January 1952, FLC, P2.1.27.

24 They are consigned in the group of drawings FLC 5627.

25 Le Corbusier, letter to Varma, 22 May 1956, FLC, P1.10.306.

26 Doshi's early proposal i.e. Plan, 10 March 1952, FLC6788. Second project i.e. Façades, 31 October 1952, FLC, 6900.

27 Daniel Siret, "Soleil, lumière et chaleur dans l'architecture moderne: Excursions dans l'oeuvre de Le Corbusier," *L'Émoi de L'histoire* 34 (2012), 177-93.

28 Ignacio Requena Ruiz, "Arquitectura adaptada al clima en la obra de Le Corbusier: La Casa de Brasil en Paris," *Palapa Revista de Investigación Científica en Arquitectura* 3, n. 1 (2013), 35-53.

29 Le Corbusier, "*Le Corbusier et Son Atelier Rue de Sèvres 35. Oeuvre Complète 1952-1957*," Willy Boesiger (ed.), vol. 6 (Zurich: Les Éditions d'Architecture, 1977), 144.

30 The explanation does not focus on this project but on all the Indian projects. FLC, P1.10.306.

31 Missenard, *L'Homme et Le Climat*, 162.

32 The systems of the English company are

also applied by engineers like Carl Rosenqvist, who collaborates with Alvar Aalto. Their official letter layout gives evidence: "*Concessionnaire des Brevets Internationaux de Chauffage par Rayonnement. Licence Crittall*". Bernard Morel, letter to André Wogenscky, 27 February 1953, FLC, N4.1.38.

33 André Missenard, *Le Chauffage et Le Rafraichissement Par Rayonnement* (Paris: Eyrolles, 1959), 25.

34 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.

35 Ets Missenard-Quint, "Maison du Brésil. Devis descriptif des travaux," 25 July 1957, FLC K1.5.277.

36 The plans of the heating systems for the ground floor (K1.9.12) and the room floors (FLC K1-9-16) as well as in the heating system description (K1.5.277), gives evidence of this.

37 FLC, K1.5.277.

38 Ibidem.

39 Roberto Gargiani and Anna Rosellini, *Le Corbusier: Béton Brut and Ineffable Space, 1940-1965. Surface Materials and Psychophysiology of Vision* (Lausanne: EPFL Press, 2011), 524.

40 FLC, P1.10.306.

4.1.5 The United Nations Headquarters and the Global Environment

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ABSTRACT

The realization of the United Nations Headquarters between 1946 and 1952 marked the onset of a complex relationship between environmental management and global development in the postwar period. Designed by an international committee of architects, the headquarters were a vexed monument to world peace. At the same time the work of the fledgling institution reflected its incipient stance on environmental and economic concerns of a global order. The 1949 United Nations Conference on the Conservation and Utilization of Resources promoted international cooperation in allocating scientific research to resource disparity as a means of keeping the peace. Scientists, engineers, and technical experts offered strategies for prosperous member states to address resource deficiencies within developing tropical and arctic regions, which were presented as the last frontiers of cultivation. Lewis Mumford remained highly circumspect regarding the UN Headquarters' representation of a new global order, questioning its unconscious symbolism of the 'managerial revolution' and monopoly capitalism. Indeed, Mumford pitted the degradations of mechanization against his theory of organic synthesis, in which science and the machine support life processes rather than diminishing them. By contrast, in his presentation of the UN headquarters Le Corbusier presented the organic in terms of an exact biology facilitated by new technology. Purportedly to address the diverse climactic origins of the UN delegates, the envelope of the UN Secretariat was designed to function as a manipulable environmental control system accommodating the global population housed within, thereby fostering harmonious relations. Internationally published and widely imitated, the details of this thin, flat, smooth surface of modernism embodied enmeshed aesthetic and technical ambitions. Drawing from contemporary discourses on technology and the organic, this paper will scrutinize the ways in which the UN invoked science to address environmental management at a global and a highly proximate level.