Heat, Air and Life: Thermodynamics and Use in Building Environments

This paper looks at a new and relatively unexplored convergence of technology and lifestyle, through the medium of architecture, as a result of the increasing "thermodynamicization" of space in the contemporary post-industrial city.

STEPHEN ROE
Feng Chia University, Taiwan

CHIAFANG WU
Tamkang University, Taiwan

INDUSTRIAL CITIES

In an early paper on the artist JMW Turner, the French philosopher Michel Serres[1] identifies the work of Turner as not just the subjective, expressive work of an artist interested in the use of paint to convey light effects but as precise portraits of a transformation sweeping society in his day. A transformation which had its origins in science and engineering but which went on to change society and culture in profound was,[2] the effects of which we are still feeling today. Unlike the Romantics who looked away from the city and industrialization to find solace in Nature, Turner became a master of portraying the Thermodynamic. For it was the new understanding of the laws of thermodynamics and their exploitation in the railways, factories, coal mines and furnaces of the period which led to the major social upheavals of the 19th century and eventually the spread of metropolitan culture. Almost uniquely Turner appears to have intuited the importance of this development and painted the transformations it wrought.

As Serres scholar Steven D. Brown writes:

> *"The very way in which Turner constructs his most famous paintings around two light sources – usually a 'hot' and 'cold' source – surrounded by undulating clouds of 'color-matter' is a way of articulating the new model of work that thermodynamics ushers in."*[3]

This emerging understanding of the actions of thermodynamics in space did have its influence in architecture, beginning with the thermodynamically engineered design of the old parliament house in London by the scientist Robert Hooke[4] and others. An understanding which gradually developed over the course of the 19th century into a sophisticated thermodynamics of building. A development which paralleled (and strove to ameliorate) the rise of the communal building –schools, hospitals,[5] prisons[6] etc. which characterized that century. These sophisticated techniques were, however, largely forgotten in the 20th century with the availability of electricity, mechanical ventilation and eventually air-conditioning.

1

Figure 1: *Rain Steam and Speed: The Great Western Railway,* 1844 by JMW Turner.[9]

POST-INDUSTRIAL CITIES

Today of course we are seeing a resurgence of interest in such techniques but their roots in the same experiments in thermodynamics of the 18th century as those which led to the industrial revolution are often forgotten. However, even if not characterized as such, today we are again seeing concern with the thermodynamic spreading beyond the former confines of the machine and into the design of buildings and cities. As Climate-Change becomes an increasing concern, the management of the thermodynamic properties of buildings –both their fabric and the air in and around them—becomes increasingly important. Today in many regulatory jurisdictions the thermodynamic performance of a building is more closely regulated than any of its dimensional, geometric, spatial or aesthetic properties.[7] With thermal properties, air changes, heat transfer all regulated and technologies like heat-pumps, heat exchangers, thermal mass, night-time flushing etc. clearly encouraged by energy-use and carbon targets –all of which rely on nuanced understanding of the thermodynamic properties of buildings. In addition, and perhaps more significant for architecture and urban design, is the influence of the Thermodynamic on the spatial and formal design of buildings, where buildings become thermodynamic instruments for the manipulation of microclimatic internal and external effects.

While these ideas originate in the internal management of buildings' thermodynamic conditions we are beginning to see their influence spread –both overtly and covertly—to the design of urban spaces around buildings. This appears to happen in two ways: Firstly the spread of the use of, formerly exclusively internal, techniques to external spaces –see for instance Foster and Partners use of a Stack to cool an external plaza in their Masdar City project.[8] Secondly we see the increasing, passively achieved, comfort levels of the internal spaces of buildings lead to a spread of the public space into the interior of the building. Where spaces originally designed to improve the comfort and energy-efficiency of a building become used as public space. This is especially noticeable in the warm climates of the Tropics and Sub-tropics. See for instance Ken Yeang's Singapore Public Library project[10] where the outdoor spaces designed as part of the cooling strategy of the building have become important public spaces both at street level (Figure 2) and above in the "sky gardens". This leads to a blurring of the boundaries between inside and out, public and private. The most remarkable example of this may be Foster and Partners Hong Kong and Shanghai Bank building[11] where hundreds of domestic workers gather on their time off to socialize in the cooler space below the building (Figure 3).

In this way the Post-industrial City can be seen as a Thermodynamic City but in a very different way to the Industrial city described by Turner and later by Serres. In the Post-industrial City the Thermodynamic is not an incidental and unfortunate result of the leaking of heat and fluids from machines into public space but rather the goal of an intentional management of heat and fluids. A thermodynamic management which acts as the precisely calibrated tool for the formation of those spaces the conditions of which are, increasingly, as carefully designed as are the visible structures and fabrics of the buildings which form them.

As we as individuals become more sensitive to this regime it becomes increasingly apparent how patterns of use and lifestyle emerge from our subconscious, corporeal understandings of the subtle climatic variations within buildings and the city; Variations which are intimately understood, and adapted to, by us as occupants. As the examples mentioned previously illustrate the thermal conditions of a space can lead to its becoming an extension of the public realm. In a hot climate, spaces which are cooler (whether through simple shading or more deliberate techniques using air movement, evaporative cooling etc.) are intuitively occupied by people through their bodies' intimate sensitivity to thermal comfort. The negative corollary of this is of course the phenomenon of the deserted plaza –found throughout the world but especially prevalent in the Tropics and Sub-tropics—where public space is provided but is rarely used because conditions rarely conform to requirements of human comfort.

Today however as we become more cognizant of the need to control thermal conditions within buildings, two things start to be observed: Firstly, architects and designers begin to apply the techniques developed for the design of building interiors to outdoor spaces, as mentioned, but secondly, and perhaps more significantly, the management of thermodynamic *difference* leads to greater differentiation of thermodynamic conditions both internally and externally. For it is *difference* in conditions which drives movement of air and fluids in and around buildings. To take the most straightforward example, the Stack Effect uses differences in temperature to drive buoyancy ventilation up through the stack and the greater the differences in temperature between top and bottom of the stack, the greater the speed of airflow.

Thus some parts of a building might be designed to be uninhabitably warm in order to drive the movement of air. This can be seen, for example, in Adrian Smith + Gordon Gill's proposal for the Headquarters building of the International Renewable Energy Association (IRENA) in Masdar, where it is acknowledged that the tops of the stacks would be –intentionally-- uninhabitable.[12] However differentiation in temperature does not always need to be so extreme. What matters most is that there is some differentiation. This introduction of differentiation means that users' or the public's sensitivity to variations in comfort conditions becomes more significant leading to differential occupation and by extension differentiated use of public space. Areas adjacent to pools --intended ostensibly to cool air before it enters a building—are instinctively identified as cooler and more comfortable and thus become more heavily occupied leading to greater social interaction. Or the shaded cooler spaces at the base of a stack –as in the Hong

2

3

Figure 2: Flashmob at the Singapore National Library.[13]

Figure 3: Immigrant domestic workers at the Hong Kong Shanghai Bank Building Hong Kong *(photo by the author).*

Kong Shanghai Bank—become favored spaces for informal gatherings which are not supported by other spaces in the city (the largely privatized internal public space of Hong Kong).

This very brief overview of some recent examples from practice reveals how, increasingly, an acknowledgement of thermodynamic performance in the design of buildings leads to the deliberate creation of non-optimal, but managed, differentiations of localized microclimatic conditions which in turn define conditions of use.

SIMULATION

Today most buildings designed to take advantage of thermodynamic difference in this way are designed using tools which simulate expected thermal, fluid and solar performance. In particular Computational Fluid Dynamics (CFD) allows us[14] to visualize the effect of differential heating and cooling. What we are interested in exploring in this paper and the projects presented is the potential for more explicit, intentional, designed or even perhaps choreographed links between this kind of --usually primarily technical – analysis and how people might occupy and use the spaces.

As CFD simulation becomes both more sophisticated and more easily available we are beginning to see its application not just to design but also to post-occupancy in order to monitor actual building performance against predicted performance.[15] This leads to the possibility of a kind of "building meteorology" where tools intended for simulation in design take on the role that weather-forecasting tools perform in the wider atmosphere. Taking in external weather conditions and providing forecasts of expected internal or adjacent conditions in and around the building.

We already see some examples of this way of thinking in some speculative architecture projects. For example Philippe Rahm in his "Domestic Meteorology" project where he creates a link between internal "meteorological" conditions and users' occupation and use of the space, even positing a kind of "weather forecasting" based on CFD simulation which would indicate to users which locations would be most favorable to their intended daily activities. What this suggests is that as computing power becomes more easily available and "ubiquitous" a kind of internal Meteorology will emerge, applying techniques from atmospheric meteorology to our urban spaces and building interiors, modelling and predicting future microclimatic behavior –principally in order to increase the efficiency of building-energy-management systems but potentially to be used by occupants to maximize comfort. Literally weather-forecasting for building and urban microclimates.

With this increased access to information and the potential for projective simulations of atmospheric conditions it is possible to imagine new synergies between lifestyle and thermodynamic environment through the interface of technology. Free permeation of such information would allow personal devices to download intensely localized meteorological predictions enabling more confident and precise calibration of urban conditions against lifestyle needs. For instance a Maps app that gives forecast atmospheric conditions in different parts of the city which would allow us to find a locale which might be ideal for what we want to do that day –a bit of jogging, sunbathing in a gentle breeze or reading a book outdoors. While this may be highly speculative we have seen in recent years how extremely unexpected technologies can quickly become everyday necessities. Current technology vectors allied with increasing interest in climate and personal wellbeing could very easily make this a reality.

Of course much of this is speculation and it must be acknowledged that there are limitations to the power and accuracy of simulation techniques –issues very dependent on the quality of input information (the perennial issue of “garbage-in garbage-out”). In addition while simulation can produce incredibly rich and intriguing information it is important that we have the ability to interpret that information and what it means for the building as atmospheric instrument. On the other hand in the last few years we have seen an incredibly rapid increase in computing power and ease of use of simulation technologies making them both more accessible and easier to interpret. Other concerns, which apply equally to all uses of such information technology, are the issues of ease of use, intuitiveness, equality of access and, of course, privacy which all need to be considered. On the other hand developments in the last few years have surprised many people by demonstrating ordinary users' appetite for and capacity to use detailed spatialized information in making lifestyle decisions[16] (and their apparent lack of concern for issues of privacy etc.).

However the usefulness of this way of thinking may be not so much in speculating on future developments but more in the way it helps us –and hopefully also the students we teach—to reconsider the relations between thermodynamic conditions, the occupation of space, how people use that space, and, by extension, the playing out of lifestyle in the city.

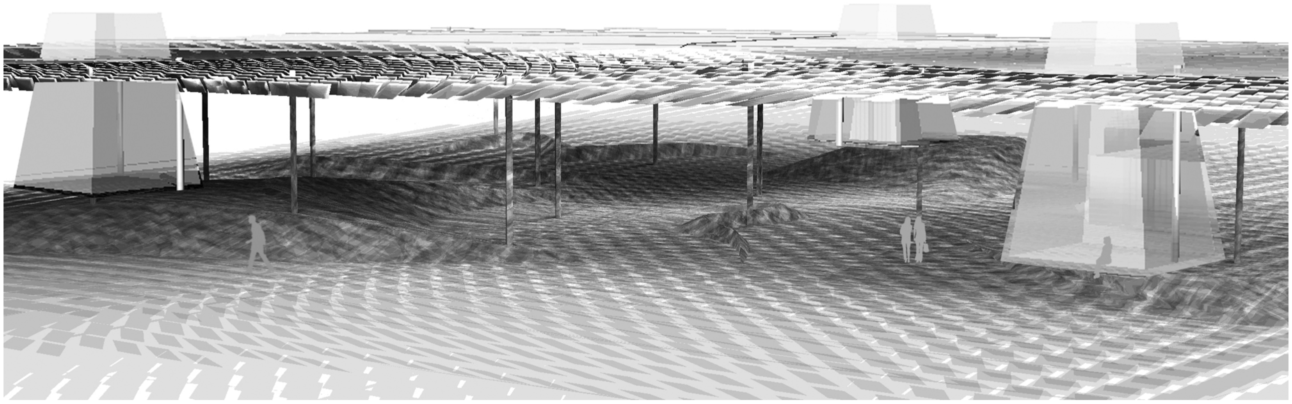
From this point of view, what is most interesting is the potential implications of these issues for architectural space and building design. To begin thinking about these questions we look briefly at the influence of a “Thermodynamic” way of working on architectural design practice, through a recent design project by our practice ROEWUarchitecture. The project is for the Sub-Tropical climate of Taiwan and attempts to extend the thermodynamic from a reactive analysis of the already-designed to a projective part of the design process. Where building and landscape are modeled to simulate conditions and are then adjusted to distribute variable conditions –thermodynamic differences— over time and space in ways which might encourage, though hopefully not prescribe programs to emerge through spontaneous activity.

WANHUA PLAZA TAIPEI

The first project is for an urban plaza in the center of Taipei. Surrounded by one of the oldest and most densely occupied districts of the city –Wanhua—it is currently an urban space but one that is rarely used and has become somewhat of a dead space.

The scheme proposes the plaza as a space between clouds and land –allowing a fluent openness between the light canopy system and the undulating landscape below. The whole plaza is open yet connected by a series of topologically varying landscape elements. These landscapes blur the boundary between the few existing historical buildings on the plaza and the ground, setting up new relations between the historical architecture and the users of the plaza. People can now approach what was previously on a pedestal.

Light plays an interesting role in a city like Taipei dictating both the thermal patterns of spaces and their uses. Open air activities can be dictated by the quality of light and the heat it produces. This design proposes a translucent panel system over the plaza to generate various intensities of light and shade. The dynamic shadow generated by this intensive light-filtering system produces areas of different thermodynamic character across the plaza, the exact configuration of which

4


changes with the day and season. These temporal spatial variations trigger various types of activities to take place. The density of shadow is controlled by the varying openness and orientations of panels which are individually fixed but vary across the whole field. At different times of the day, for instance in the morning, people gather to practice Tai-chi in soft shadow but at noon the intense shadows provide shade for residents or tourists to have lunch in the park.

Using the thermodynamic principle that air moves from cool areas to warmer areas –from areas of high pressure to areas of lower pressure—we set up a deliberate differentiation between a series of stacks which are allowed to heat up and the shifting areas in shade. This differentiation causes air to move from shaded areas towards the stacks producing a series of pleasant breezes within the space. However as the sun moves across the sky the shaded areas drift across the plaza and the locations and the directions of the breezes change setting up a constantly varying relation between shade, wind and landscape.

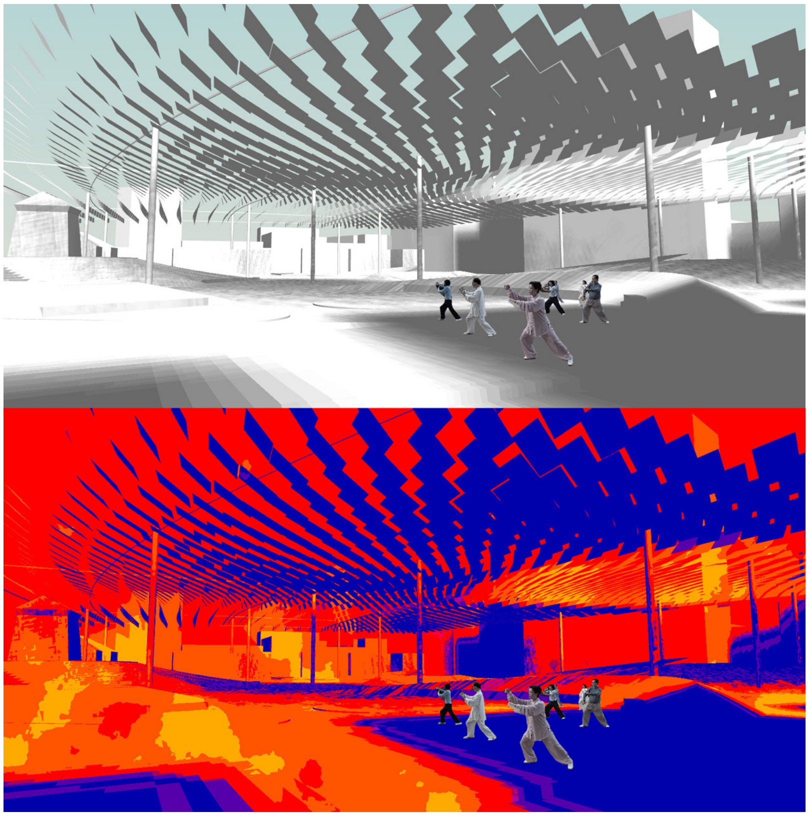
Rather than prescribing specific activities for particular spaces the project proposes a constantly changing series of atmospheric conditions which vary over time and space. These, in conjunction with the varied landscape below, provide a series of "affordances"[17] for different activities to take place. The design process employs simulation –of light and air- to try and align potential conditions to most likely activities –for instance making sure that shade and cooling breezes are available for Tai-chi exercise in the early morning during summer months, or that adequate shaded areas are available at lunchtime in spring and fall when they are most likely to be used. But, in general, uses at particular times would not be prescribed. Use would emerge from engagement with prevailing thermodynamic conditions as a result of inherent human sensitivity to those conditions and our innate ability to search out greater comfort. The shading structure acts more like a meteorological instrument inserted into the micro-climate of downtown Taipei to affect the thermodynamics of the plaza in real but intentionally indeterminate ways.

Overall the design deliberately eschews monumentalism or symbolism in favor of a somewhat difficult to discern appearance which results from the conjunction of the floating canopy and the undulating landscape. The character of the plaza would emerge from the conditions it creates and the ways in which it is occupied and used. A thermodynamic field is created between ground and sky which elicits its performances both material and cultural, technical and social which through comfort and discomfort, alignment and conflict, lead to new relations between building, landscape, city and lifestyle.

Figure 4: Aerial view of the Wanhua Plaza project.

ENDNOTES

1. Serres, M. (1982) Hermes: Literature, Science, Philosophy, edited by J.V. Harari and D.F. Bell. Baltimore, MD: Johns Hopkins University Press.



5

Figure 5: Comparison of conventional and "thermodynamic" visualizations of the conditions and potential occupations of the Plaza.

CONCLUSION

As simulation techniques become more available to architects and the means to adjust and fine-tune models becomes easier, the thermodynamic becomes a way of conceiving the city and the building not just in terms of their physical form but also in terms of their operation -not so much as the prescriptive "machines for living" of Modernism but more as predictive and dispersed mechanisms for producing variable climatic "affordances" for human activity to take place, activity which is not prescribed but emerges as a result of interaction between human desire, atmospheric conditions and the technologies to achieve them.

JMW Turner began his career as a "Topographic Artist" producing incredibly precisely delineated drawings and paintings of architectural monuments. Under the influence of the increasingly thermodynamic conditions of his day however his work moved to ever more nebulous but paradoxically "real" portraits of the changing atmospheric conditions of the industrial city. Today, as the Thermodynamic becomes even more pervasive and important in our post-industrial urban centers, we will perhaps see an equivalent move away from the precisely delineated contour of form to the documentation and even manipulation of atmospheric effects through the instrument of architecture. Crucial to this process is the ability to visualize and manipulate thermodynamics in and around buildings. The techniques to do this are becoming rapidly more easily available and user-friendly. However their importance lies not in themselves but in what they can potentially tell us about our changing perception of space and the city –to, on the one hand, understand the reciprocal relations between building form and thermodynamics and, on the other hand, to potentially encourage a more informed and nuanced understanding of the relationship between such atmospheric conditions and daily life.

2. Global Warming, the current crisis we find ourselves dealing with, has its origins in this period with general recognition that greenhouse gas levels have risen as a result of and beginning with the process of industrialization.

3. Steven D. Brown: "Michel Serres Science, Translation and the Logic of the Parasite" in Theory, Culture & Society 2002 (SAGE, London, Thousand Oaks and New Delhi), Vol. 19(3): p. 5.

4. See for instance Tomlinson, Charles A Rudimentary Treatise on Warming and Ventilation, John Weale Architectural Library, London 1850. The ventilation of the House of Commons is described on pp.214-219.

5. Reyner Banham, The Architecture of the Well-Tempered Environment –see Chapter 2 "A Dark Satanic Century."

6. See Tomlinson op.cit. pp. 244-246 for a description of the ingenious ventilation of Pentonville Prison designed by one Major Jebb where flue sizes and in-use air change rates are given.

7. See for instance the Building Regulations of the UK which stipulate increasingly strict thermal performance, air-changes etc, but make no mention of minimum space standards.

8. See "Masdar City Master Plan: The Design and Engineering Strategies" by Mathias Schuler in Peter Droege ed. 100% Renewable: Energy Autonomy in Action, Earthscan, 2012 p. 248.

9. Public domain image –see: http://en.wikipedia.org/wiki/File:Rain_Steam_and_Speed_the_Great_Western_Railway.jpg accessed 29/04/2014.

10. Ken Yeang, T.R. Hamzah & Yeang Singapore Library. The authors' own visits to this building have seen its passively cooled semi-outdoor spaces used for public events at the ground level or at the upper levels as informal social spaces (the sky gardens).

11. See Marco, Cenzatti "Heterotopias of Difference" in Michiel Dehaene, Lieven De Cauter (eds.) Heterotopia and the City: Public Space in a Postcivil Society, Routledge, 2008 p.74.

12. Adrian Smith + Gordon Gill IRENA Headquarters Building, Masdar –see: http://smithgill.com/work/masdar_headquarters/ accessed 29/04/14.

13. Source: http://shoutout.omgparadise.com/data/attachments/2013/06/24/1_bB1IiwfR3BDJi237dy3B_large.jpg accessed 29/04/2014.

14. Increasingly "us" includes architects as well as engineers as easy to use software like CFDesign (now SimulationCFD) becomes more available and desktop computers have the power to run these kinds of software.

15. Oliver Kinnane, Tom Grey, Mark Dyer: "A Comprehensive Monitoring System to Assess the Performance of a Prototype House" In: Sustainability in Energy and Buildings, Smart Innovation, Systems and Technologies Volume 22, 2013, pp 373-379.

16. For instance using Google Maps to find a restaurant etc.. While these are relatively mundane and predictable uses, more unexpected --and to many of us invasive-- applications are already proving popular.

17. "Affordance" is a term from ecology which has been defined as: "a relationship between an organism and the environment that signals an opportunity for or inhibition of action" see: Leo van Lier (2004). "Relations". e-Study Guide for: Handbook of Psychology, Volume 6: Developmental Psychology: Psychology, Human development. Springer. p. 4.