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Energy-Performative Architecture

Working with the Forces of Nature to Optimize Energy Flows and the Impact on Phenomenology of Architectural Form

Brian Cody

Introduction

Early on in the history of building, an intelligent energy concept, which made efficient use of prevailing natural forces, was of fundamental importance, primarily due to a lack of viable compensation possibilities. This situation more or less endured until the early twentieth century, when in the aftermath of the Industrial Revolution the introduction of fossil-fuel-powered climate control and lighting systems finally "liberated" architecture entirely from the necessity to work with natural forces and began instead to combat them with imported energy. This culminated in the modernist movement and the so-called international style made possible by these technologies (Behling, 2000).

Thus began a period during which it was possible to have architecture which was in many ways unquestionably very good, yet very inefficient in terms of energy use, perhaps exemplified by the international style. And although there has been important work throughout the period since, which has gone against a mainstream of climate-defiant architecture, particularly after the energy crises in the 1970s and at the end of the twentieth century due to concerns about global warming and climate change, this has always been confined to the margins of mainstream architecture. For the most part, the emphasis has been on improving the efficiency of building typologies, which retain in essence the same forms employed by their inefficient fossil-fuel-powered ancestors, albeit improved through increased thermal insulation, more efficient climate control systems and the integration of renewable energy technology.

Building energy performance can be defined as the relationship between the quality of internal environment achieved in a space and the quantity of primary energy required to maintain this internal environment (Cody, 2008). Achieving a high level of energy performance in building design necessitates the use of natural forces. In the context of buildings, these are forces which arise due to natural processes in the buildings environment and which can be harnessed to meet the energy demand required to make a building comfortable or drive processes required for its use and functionality. These forces primarily arise as a result of solar and wind energy but also due to temperature differences between various ambient sources and sinks which allow certain heat flow processes (e.g. ground water or geothermal energy use) to occur.

A building is designed to operate within a natural environment of continuingly changing conditions and provide internal conditions, which diverge significantly from these most of the time. Two approaches can be followed to achieve this goal. The conventional approach is to exclude the external environment as much as possible and employ mechanical systems to provide the desired internal conditions. An alternative approach is to design the building's form, construction and skin to capture and utilize energy flows in the environment, in order to create the desired internal conditions. This second approach, in which the energy of the dominant natural forces, which seem to pose the problem – e.g. wind for a skyscraper, solar radiation in a hot climate, daylight for a museum building – are captured and used in a controlled way to achieve the desired result, is for obvious reasons the more challenging. It also, however, offers greater potential with regard to the efficient use of resources.

Energy design is essentially the use of natural forces and is a fundamentally new way of collaborating on the design of buildings. In the energy design of a building, concepts are developed which minimize building energy demand while optimizing internal environmental conditions in the spaces. Instead of deploying standard solutions, the scientific principles of thermodynamics, heat transfer and fluid mechanics are invoked and applied, in order to develop solutions which use multifunctional building elements and systems to maximize building performance.

Energy strategies in the form-finding process of building design can generate new architectural forms and lead to new aesthetical qualities in architecture and urban design (Cody, 2017). Energy-performative buildings achieve high energy performance due to their architectural concepts and strategies. These are not buildings which merely incorporate technologies to improve energy performance, with no resulting influence on the architecture. The high level of energy performance considered here is achievable only by designing the architecture from the outset with high energy performance in mind.

Architectural form can be influenced and shaped by energy design, both in terms of the appearance of a building in general and the architectural elements and means of expression used to determine this, as well as in terms of its external physical shape. Energy design strategies also impact on the phenomenology of the architectural form, the way architecture is experienced or perceived by all the senses in a real physical interaction between a person and a building – arguably the way all architecture should finally be evaluated. This refers to both the experience of someone inside a space as well as of someone outside the building – normally at street level. These are the ways a building ultimately impacts on people in an immediate physical sense and I would argue that the process of designing a building entails approaching the design simultaneously from both of these perspectives, i.e. from within and without.

In considering the impact on phenomenology of form, we should be less concerned with the appearance of the form and more with how it is experienced. The focus of architectural discourse, education and of course practice has long been heavily focused on visual aspects. Of course, architecture can be treated as art, to be visually appraised and enjoyed. Of course, our visual perception is also the most important sense for collecting information. However, architecture needs to be more than this. Architecture is about how we experience the spaces with all our senses, both within buildings and in the spaces between buildings in our cities. It is the quality of this total experience, which determines the true value and quality of our built environment.

The environmental aspects of buildings account for a large part of our experience in buildings. A space feels too warm or too cold. We perceive the air to be stale or fresh or possibly we feel uncomfortable due to high air speeds in the form of drafts. The odors, the noise level and spatial acoustic characteristics (e.g. reverberation time) are pleasant or otherwise. The systems to control the internal environmental conditions also often account for a large part of our interactions with a space and therefore our experience of the space. An experience many of us are familiar with is the first night in an unfamiliar hotel room, especially if you arrive late. The interactions with the lights, windows, shading and HVAC (heating, ventilation and air conditioning) systems provide for multifarious experiences, not all of them of the pleasant variety.

One of the primary tasks of a building design is to create comfortable spaces. And this is easier said than done. The result of good energy design is a good internal environment, not the systems to achieve it. The energy design approach uses building form, skin and construction to modify the sea of ever-changing conditions the external climate of a particular location offers up and bring it as close as possible to the desired internal environmental condition, thus minimizing the energy demand of the climate control systems. In energy design, the focus and aim of the design is a building with an optimal internal climate, minimized energy demand and a high spatial quality. The materials, technical systems, etc., used to achieve these goals are merely elements of the solution and not aims in themselves.

Case Studies from Contemporary Practice and Recent Research

In order to explore the relationships between energy, architectural form and its phenomenology, I will use case studies from recent research and contemporary practice, in which I have been involved in over the course of the last 30 years.

In the early 1990s, shortly after the Berlin Wall came down, one of the first of a new generation of ultra-low-energy buildings was to be constructed in former East Berlin; the pioneering Low Energy Apartment Building in the Marzahn district (Assmann Salomon & Scheidt architects). At the outset of the design process, I convinced the client to make a radical departure from the conventional design process in which an architectural design concept is prepared and subsequently optimized in terms of energy performance, and instead, as an initial step, carry out studies to find the optimal form to incorporate the required building program in terms of energy performance, the results of which were then used to generate the architectural design (Hawkes, 2002). The final form has a large curved south-facing façade with a high proportion of glass while the area and glazed proportion of the north façade are minimized (Figure 20.1).

The building is structured in three thermal zones: the living rooms on the south side, an unheated buffer zone on the north side, in which the staircases and lifts are located, and the rooms requiring the highest internal temperatures, the mechanically ventilated bathrooms, in the middle. The projecting balconies on the south side provide effective shading in summer but allow the lower winter solar radiation to penetrate into the apartments. Sliding doors in the walls separating the rooms on the south side enable the sun to reach deeper into the spaces and also allow a more flexible use of the spaces (Figure 20.2).

For the Braun headquarters building near Frankfurt in Germany (schneider + schumacher architects), built in 2000, a high-performance double-skin façade was developed, which gives the external appearance of a smooth glass façade while improving the thermal and energy performance of the skin to a level which enabled the mechanical systems required in the building to be significantly reduced, allowing mechanical ventilation and conventional heating systems to be dispensed with (Figure 20.3).

A network of capillary tubing integrated into a thin plaster layer on the underside of the concrete slab, which is fed with warm water in cold weather and cool water in warm weather, is the only system needed to provide comfortable internal conditions in the offices (Figure 20.4).

The building skin comprises two layers with a separating membrane provided in the façade cavity at each floor level and for each façade planning module. Each module has an external window, which is automatically controlled, and a narrow vertically aligned opaque element in the inside skin which is manually operated for ventilation. The shading device is located in the cavity. In the middle of the U-formed building plan, a central atrium is formed with a polytetrafluoroethylene (PTFE) foil cushion roof construction which provides the second skin for the office façades facing into the atrium, which is

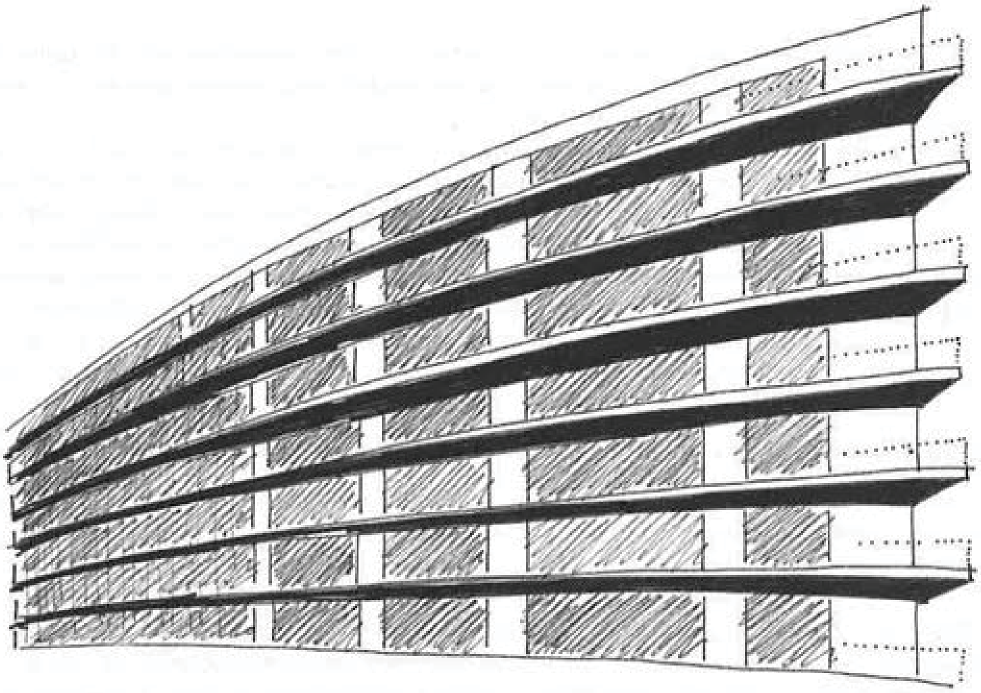

Figure 20.1 Low Energy Apartment Building, Berlin, south view.
Source: Brian Cody

Figure 20.2 Low Energy Apartment Building, Berlin, apartment.
Source: Brian Cody

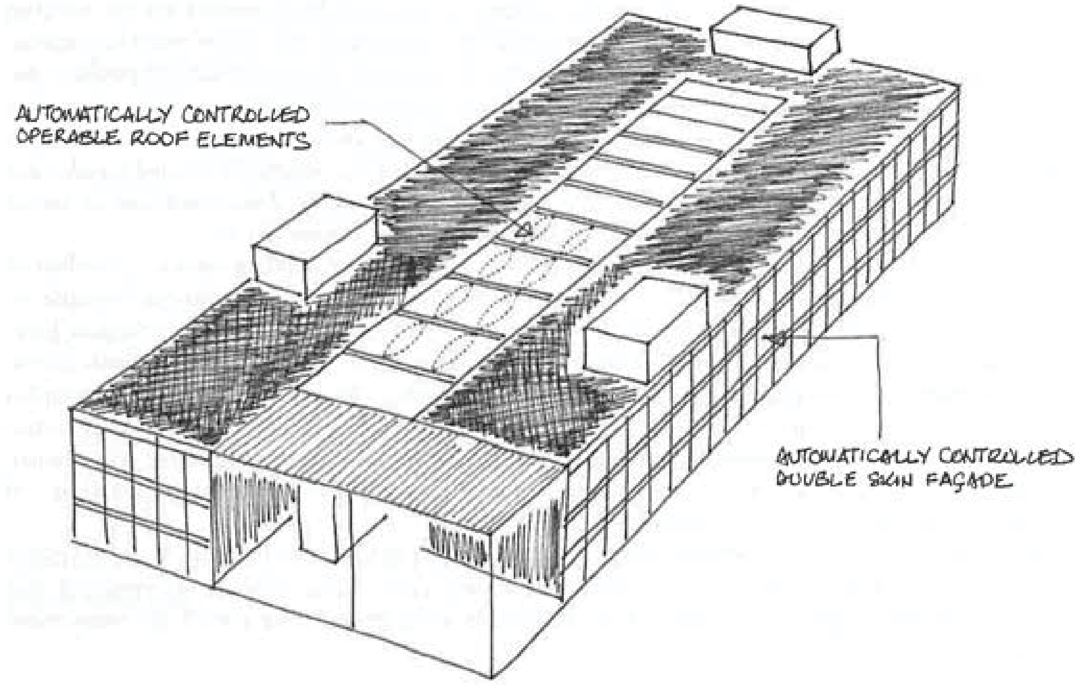

Figure 20.3 Braun HQ Germany, double-skin concept.
Source: Brian Cody

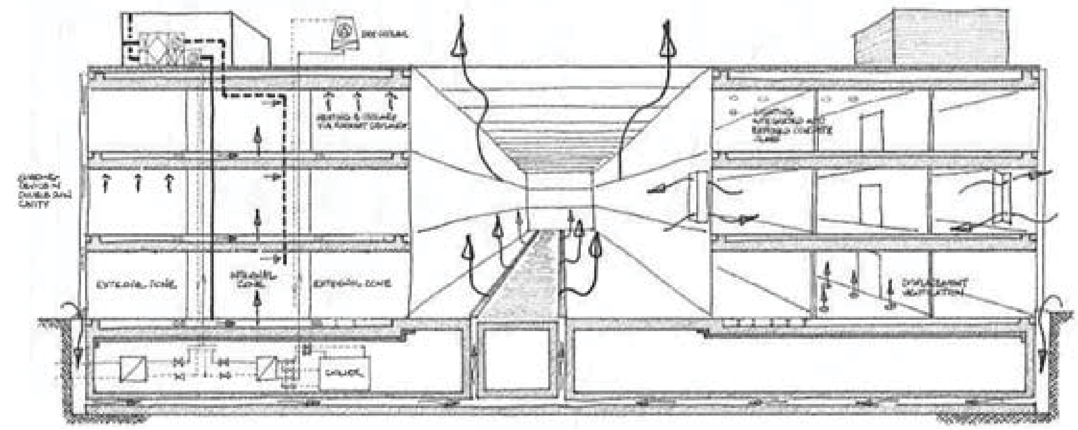

Figure 20.4 Braun HQ Germany, energy concept.
Source: Brian Cody

an unheated buffer zone. The outer skin of the building is automatically controlled via the building management system. Inspired by the example provided by human skin, the façade reacts to ambient outside conditions, the outer layer opening and closing in response to external air temperature and user behavior, while the shading device in the façade cavity is controlled in response to incident solar radiation. The sensory environment provided by the radiant heavyweight ceiling slabs, the opaque vertically aligned elements for natural ventilation, the fully glazed but effectively shaded façades and the automatic control system of the smart skin also provided a unique spatial experience for its occupants when completed at the start of the twenty-first century (Figure 20.5).

For the Duales System Pavilion at the EXPO 2000 in Hanover, the building owner, a provider of take-back packaging systems, wanted a pavilion which avoided overheating without recourse to conventional air conditioning in line with their corporate philosophy of a closed ecological loop. The anticipated large number of visitors in the summer months and the high internal loads due to exhibition lighting and equipment, together with the wish that the pavilion could be dismantled after the EXPO and rebuilt somewhere else, provided a substantial challenge. Conventional thermal mass in the form of a heavyweight building structure was obviously not an option. The design, developed with Atelier Brückner in Stuttgart, responds to this challenge with the provision of thermal mass which can be easily transported (Figure 20.6).

Water tanks, which can be emptied and re-filled after moving to a new location, were integrated into the spiraling lightweight steel construction exhibition ramp. Spray nozzles incorporated into the façade allowed water to be sprayed from the façade at night and thus cooled by evaporation (Figure 20.7).

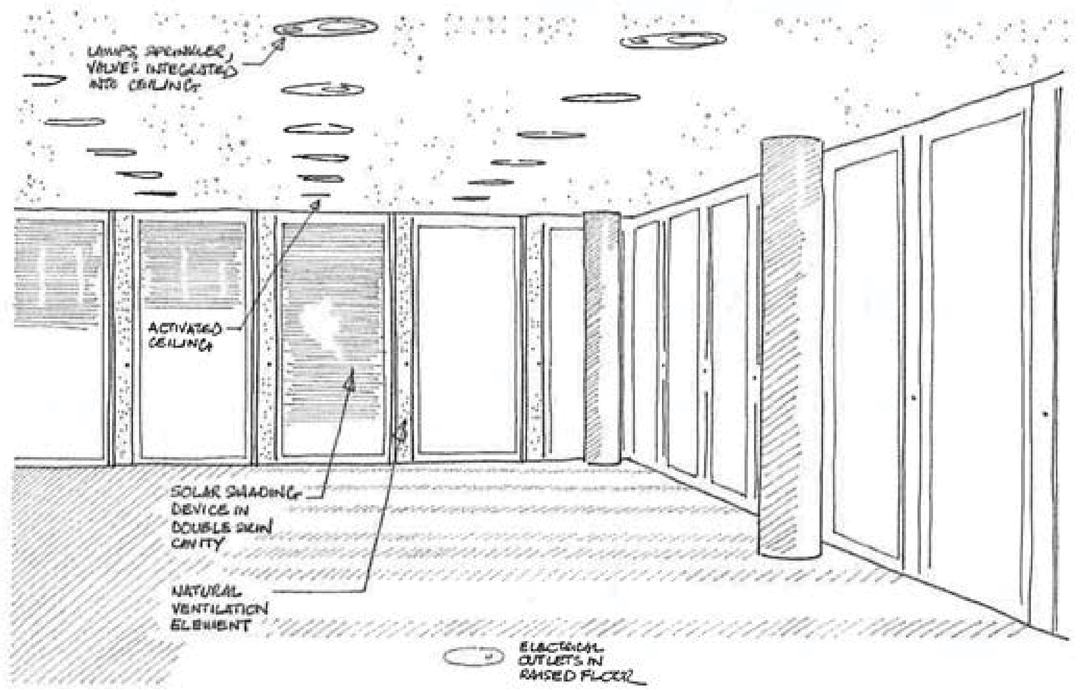

Figure 20.5 Braun HQ Germany, office interior.
Source: Brian Cody

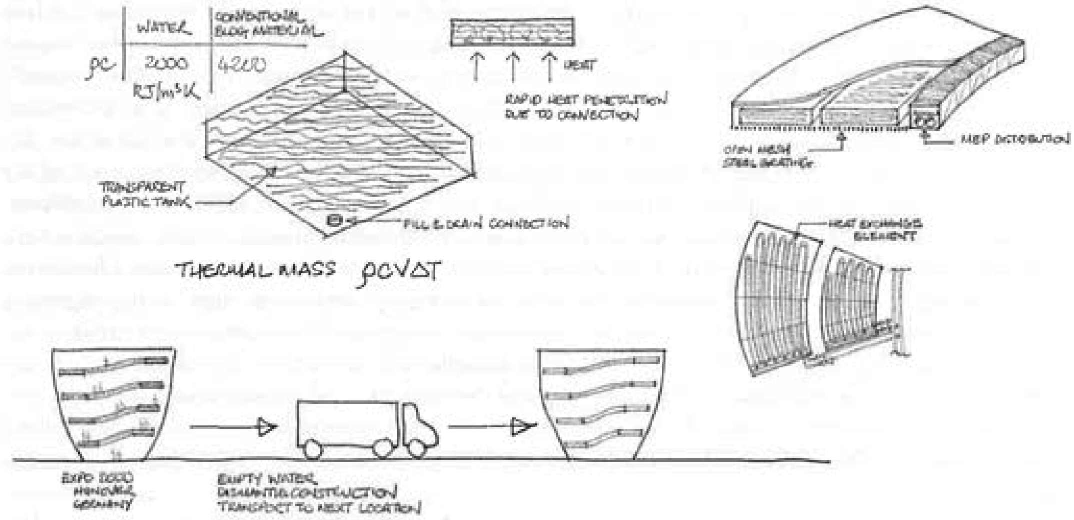

Figure 20.6 DSD Pavilion, EXPO 2000, approach.
Source: Brian Cody

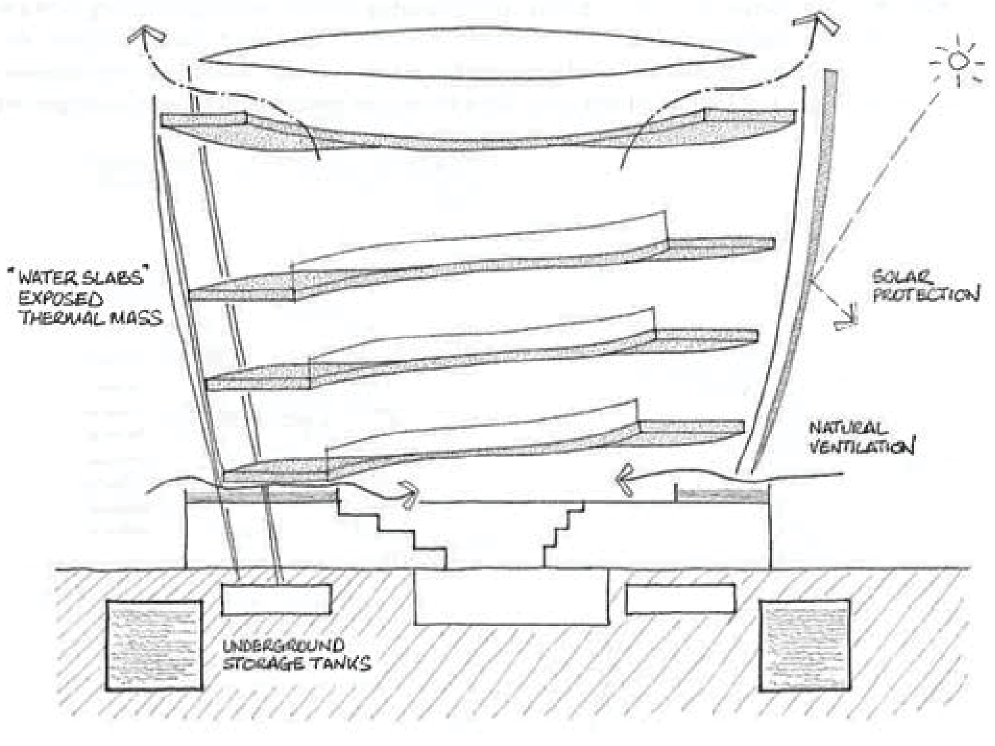

Figure 20.7 DSD Pavilion, EXPO 2000, concept.
Source: Brian Cody

This water was circulated in a secondary circuit coupled to the water tanks by means of heat exchanging tubing. The thermal mass could thus be activated and cooling energy regenerated. Similar to the way humans and some animals perspire to lose heat in warm conditions, the building "sweats". In the case of the pavilion, this does not occur as a direct response to overheating as in the natural world, but at nighttime when it is cooler, in order to regenerate itself for the anticipated hot day ahead. The concept of an ecological closed loop embodied in the concept of the Pavilion matched the corporate philosophy of the building owner so well that it was decided to include it in the exhibition. The energy design concepts became part of the exhibition, including monitors with touch screens which allowed visitors to interact with the building and its systems and take part in a virtual simulation of the building's energy systems, whereby the effect of changing parameters such as the nighttime evaporative cooling system operation could be experienced, or data on the real-time operation of the systems viewed. The influence of the energy design strategies did not stop at the architecture of the building containing the exhibition but became a part of the exhibition experience itself.

The OEVAG bank headquarters building in Vienna city with Carsten Roth Architects, completed in 2010, brought forth a completely new typological solution for an office atrium building (Figure 20.8).

Cellular offices, providing space for concentrated working, form an external ring facing the surrounding streets in a perimeter block formation, while communication spaces and circulation elements form independent structures, which are inserted into a large interstitial atrium space within the office ring. This spatial structure ensures equal quality for all working spaces and creates a dynamic vertical atrium space, which encourages and supports informal communication and incorporates circulation elements and shared areas (meeting rooms, etc.). The special areas requiring a more intensive building services infrastructure are grouped together and thus more efficiently served. In terms of energy demand, the solar load for the special areas is significantly reduced and the compact design reduces the transmission heat losses of the building considerably. In this case, the influence of energy performance strategies on

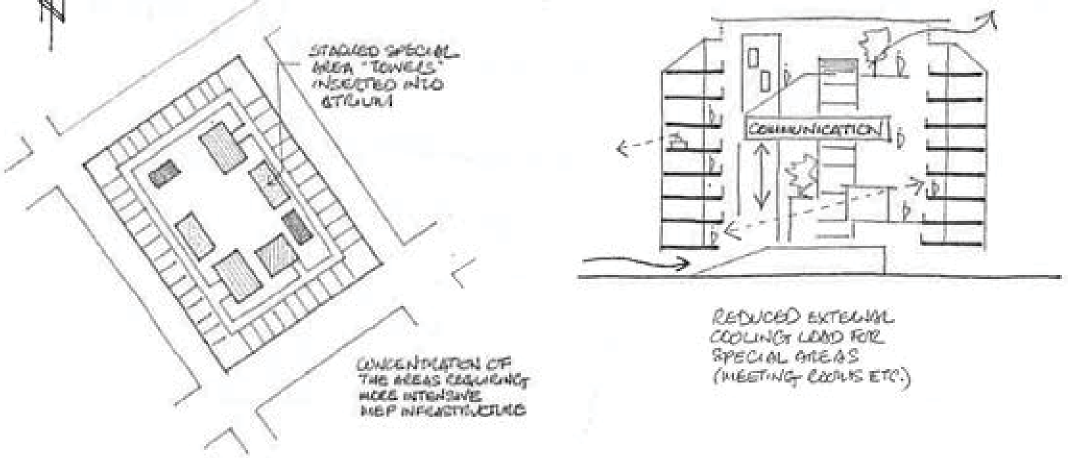

Figure 20.8 OEVAG bank HQ, Vienna, conceptual approach.
Source: Brian Cody

form is not visible in the outer building form or in the façade composition but is evident in a subtler way – in the configuration of the building, in its floor plan and section. The very specific building form also offers a unique spatial experience.

The form of the new headquarters building for the European Central Bank in Frankfurt (Coop Himmelb(l)au architects), completed in 2014, was strongly influenced by considerations to maximize building energy performance and employ wind and thermal buoyancy to provide controlled natural ventilation of the offices (Figure 20.9).

A double skin was wrapped around the two towers to create a central atrium and double-skin façades on the external sides of the towers. The atrium was horizontally divided up into three sections with a height of approximately 60 meters each, in order to keep the pressure differences between floors manageable. Functional areas (meeting rooms, recreation zones, communication bridges, lifts, etc.) were moved out of the office towers and into the atrium, allowing more efficient spatial organization of the office towers. The dynamically formed atrium connects the two towers and improves communication within the building complex. The façade incorporates selective glazing, effective quasi-external automatically controlled movable solar shading and specially designed operable elements, which allow natural ventilation during a large part of the year. The naturally ventilated atrium is a buffer zone with minimal thermal conditioning, offering spatial and communication potential in the form of a vibrant vertical city. The office workers arrive and leave their working spaces every day by passing through this remarkable space with magnificent views of the city of Frankfurt but also with a sense of connection to the whole spatial volume containing the institution: the element of vertical connectivity often missing in high-rise office buildings. The use of the specially designed natural ventilation elements in the

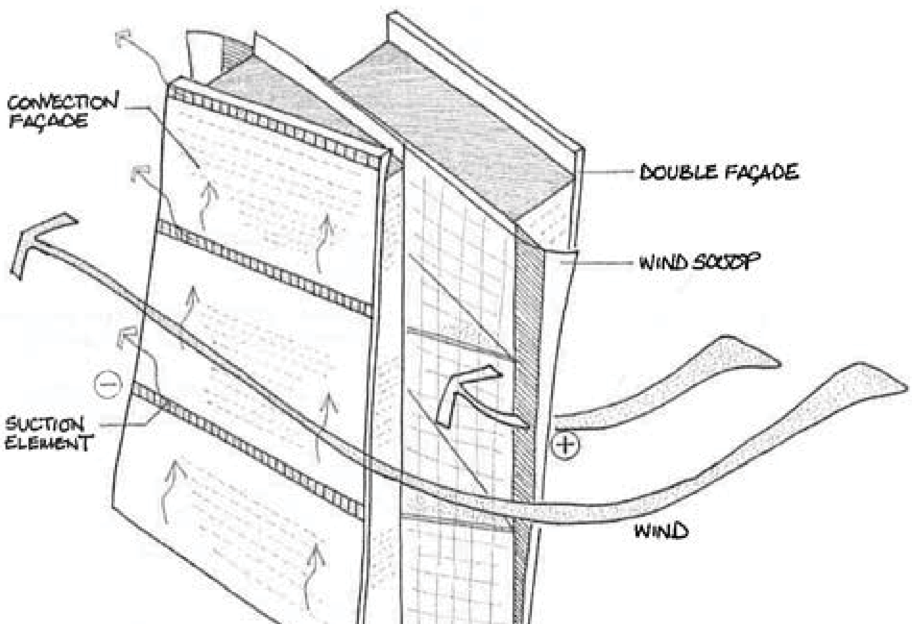

Figure 20.9 European Central Bank HQ, Frankfurt.
Source: Brian Cody

façade provides a direct relationship with the ambient environment, allowing the passage of fresh air from outside but also olfactory and auditory aspects of the surroundings to permeate and color the perceived experience indoors, in a fundamentally different way to conventional concepts employed in high-rise office towers, which tend to eschew this connection with the outside through the use of sealed building envelopes.

In the design of the NRW archive building in Duisburg, Germany with Ortner + Ortner architects, one of the most important design decisions was taken at the start of the design process during the competition phase. The program was archive space for the storage of important government papers, together with the necessary office working space. Due to the hygroscopic nature of paper, constant internal environmental conditions must be maintained, in order to prevent damage to the documents (especially harmful are rapid fluctuations in relative humidity) and thus this type of building is usually fully air conditioned. An old corn storage building was located on the site and was to be preserved. Very early on in the design process, we adopted a radical solution, in which the two functions of document storage and office working were completely separated, thus altering the conventional operational structure of the organization (Figure 20.10).

The existing windows in the corn storage building were closed up and this building was extended and used for the archive spaces, while the working spaces for the employees were provided in a new office building alongside. By removing the external thermal loads via the windows and the internal thermal loads by providing no working spaces in the archive facility itself (people enter via air locks to collect or return the documents), it was possible to maintain the necessary stable environmental conditions in the archive with help of the exposed thermal mass of the structure and with minimal technical systems

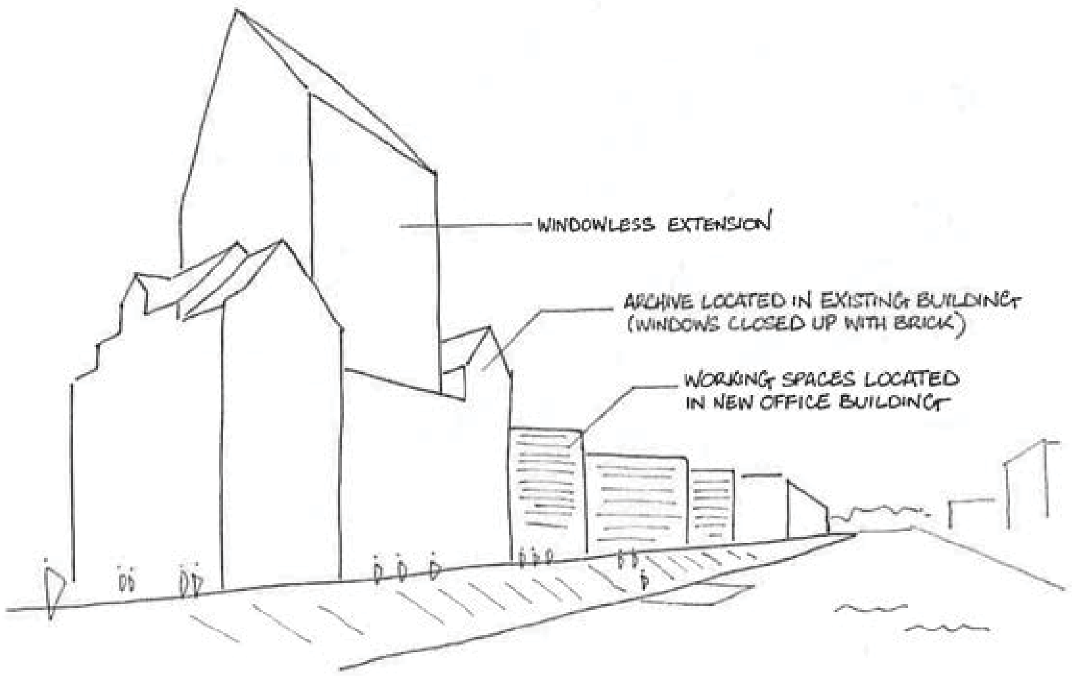

Figure 20.10 NRW state archive building, Duisburg, Germany.
Source: Brian Cody

and energy input. By configuring the program such that the office spaces and the archive are separated and housed in structures with very different characteristics, the necessary thermal conditioning of the archive building, which was completed in 2014, can be largely achieved by passive measures and the existing historical structure could be used to maximum effect.

With OMA architects we developed a new university campus building typology for the École Centrale Paris building, completed in 2017, which achieves high energy performance by utilizing synergetic interactions between the various uses while creating a new form of campus space under a "climate envelope". The building comprises teaching spaces, laboratories and offices for an engineering school, all enclosed within this climate envelope, so that the in-between spaces form an indoor campus. Placing the envelope around the whole campus volume instead of around individual buildings reduces the amount of heat transfer area to outside and creates a unique spatial environment between the program of offices, laboratories and teaching spaces (Figure 20.11).

Within the climate envelope, composed of a PTFE foil roof and glass façades, a macroclimate is created, which is not as closely controlled as the internal environments within the laboratories and the offices. This transitional space between the internal and external environments supports and enhances the campus atmosphere and informal communication. The specific typological approach works to enhance both communication between people and synergetic energy flows between the many diversified uses under its roof, transferring surplus heat from the laboratories to spaces which require heat, such as the offices (Figure 20.12).

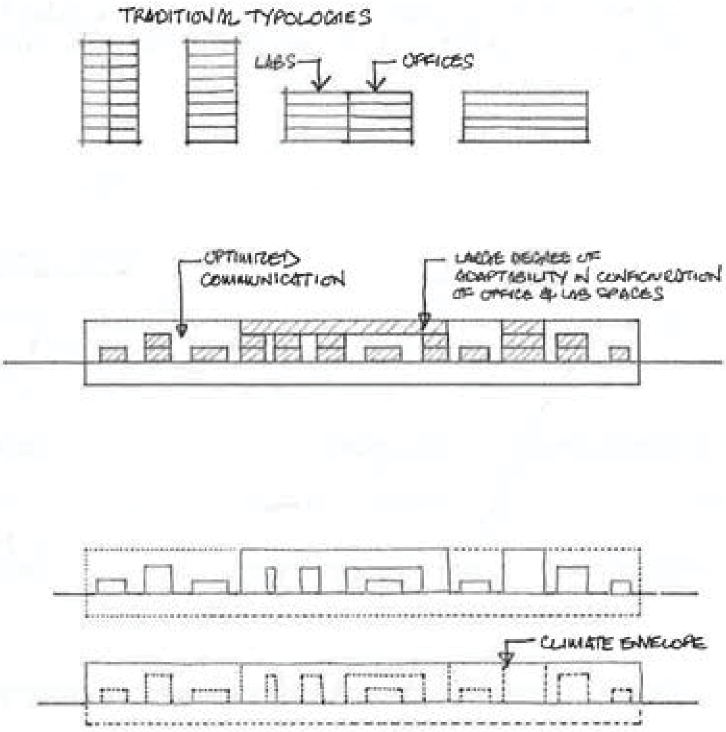

Figure 20.11 École Centrale Paris, typology considerations.
Source: Brian Cody

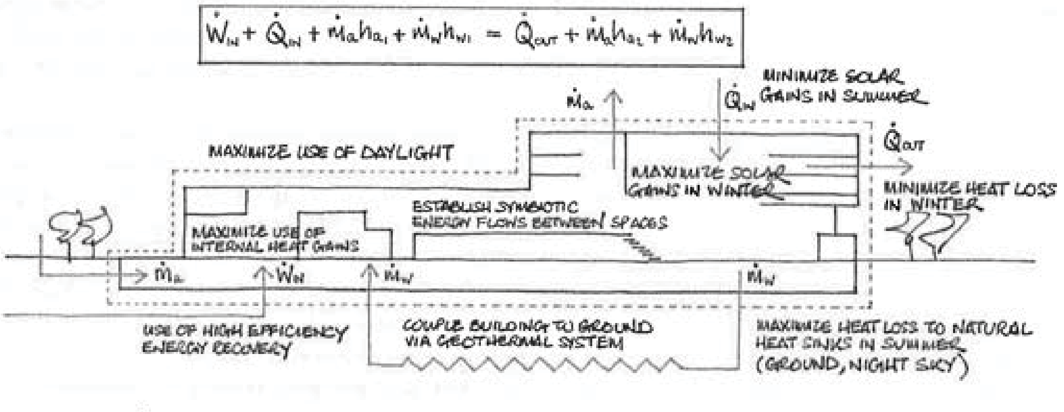

Figure 20.12 École Central Paris, energy concept.
Source: Brian Cody

The user experience of space at both the university campus level and within the teaching and research spaces themselves is unique and differs substantially from the experience in conventional typologies.

In the first-prize-winning design in the competition for the new Adidas office building in Herzogenaurach, Germany in 2014, in collaboration with the architects DMAA, we developed a very-deep-plan building form in defiance of the prevailing conventional wisdom in Germany

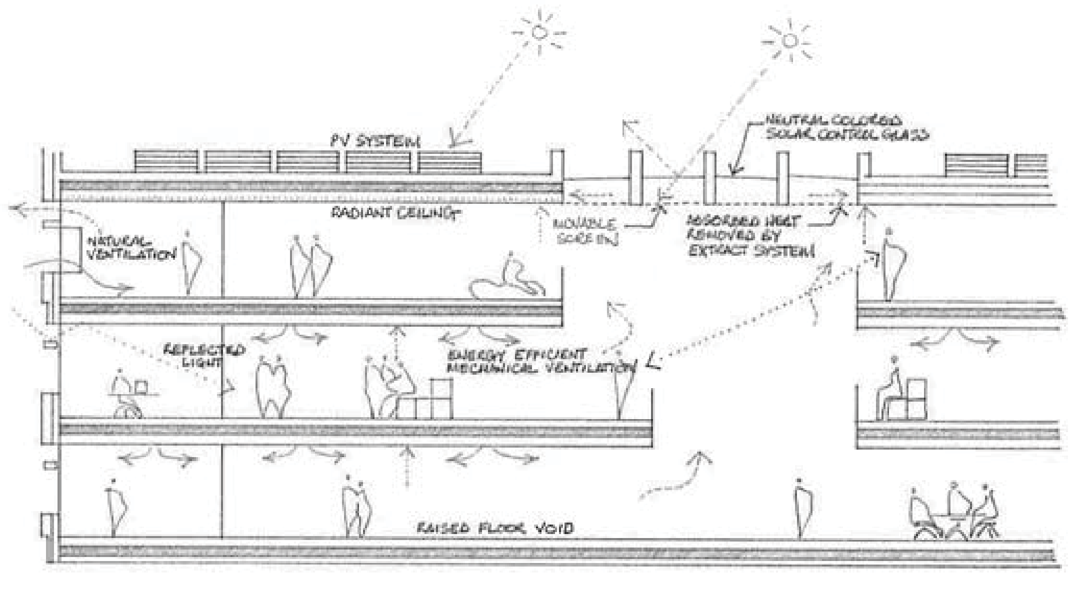

Figure 20.13 Adidas Office Building, energy concept.
Source: Brian Cody

that an energy-efficient office building should have a shallow floor plan for natural light and ventilation. Instead, the design comprises office platforms within a large volumetric enclosure offering a unique three-dimensional working environment (Figure 20.13).

Strategically placed voids introduce and distribute natural light and the entire roof is used for solar electricity production. The reduced grey energy due to the compact form and much-reduced façade area together with the increased energy production of the large roof surface more than compensates for the increased artificial lighting demand in the internal zone of the building, so that the proposed design not only offers a new and unique spatial environment, which meets the special needs of the company, but also achieves enhanced energy performance.

In 2016 we completed a study for the real estate developer ARE (Austrian Real Estate), in which the task was to develop concepts for a radically different approach to the construction of apartment buildings and subsequently monitor their implementation in pilot projects across Austria. The point of departure was a five-year development program for privately funded housing. A small group of interdisciplinary experts was formed, and working closely with Cino Zucchi in Milan and Elsa Prochazka in Vienna, I proposed an energy concept employing a layered-skin construction, which incorporates strategies to provide energy-efficient ventilation and maximize energy performance, while at the same time offering an extension of inhabitable space depending on external conditions. Two important aspects to be addressed by the project were the increasingly strict requirements for building ventilation (user-independent ventilation to prevent building damage caused by high internal humidity and the provision of operable windows for natural ventilation at locations with high external noise levels) and the rapidly rising increase in nationwide electrical energy demand, in part caused by measures introduced to increase energy efficiency of the building stock. The developed concepts allow the creation of different thermal zones leading to new spatial qualities. The double-skin "smart façade" reacts to changes in external and internal conditions, providing tempering of the incoming supply air, maximizing passive solar energy use in winter and providing effective solar protection in summer, and is to be constructed using timber module construction. Large radiators constitute a fast-reacting heating system which can provide a response that is temporally and spatially aligned to the actual demand, so that the spaces are only conditioned when required. They also provide cooling and some dehumidification in summer.

In effect, the complex multilayered external walls and the ubiquitous mechanical ventilation systems used in present-day construction methods are replaced with inhabitable space (Figure 20.14).

Options were explored in which the second skin is extended over the roof with shared space provided at the ground floor and top floor levels, so that not only are conventional walls eliminated but also conventional roof and ground floor constructions. The approach leads to a very different experience of space in many ways. During a large part of the year, particularly during the so-called changeover seasons, the living space is extended by opening up the inner façade completely by sliding the glass panels to the side. Operable elements in the façade open and close automatically in order to maintain the required air quality, based on measured CO2 concentration and relative humidity levels (Figure 20.15).

The use of "radiators" – traditionally used for hydronic heating systems – for cooling and dehumidification leads to visible condensation of the moisture-laden air in summer on the radiator surface, thus impacting on both the visual and thermal experience.

The strategies employed emphasize the use of natural forces, especially the sun, to achieve high performance instead of the more conventional approach of protection against the external environment with very high levels of insulation and airtight construction. To study the effect of unfavourable user behaviour on the performance of the concept, we studied this aspect in both the proposed and conventional concepts. Interestingly, the proposed concepts showed clear advantages when compared with conventional low-energy concepts such as the "passive house" concept, as the sensitivity to occupant behaviour was shown to be much less pronounced.

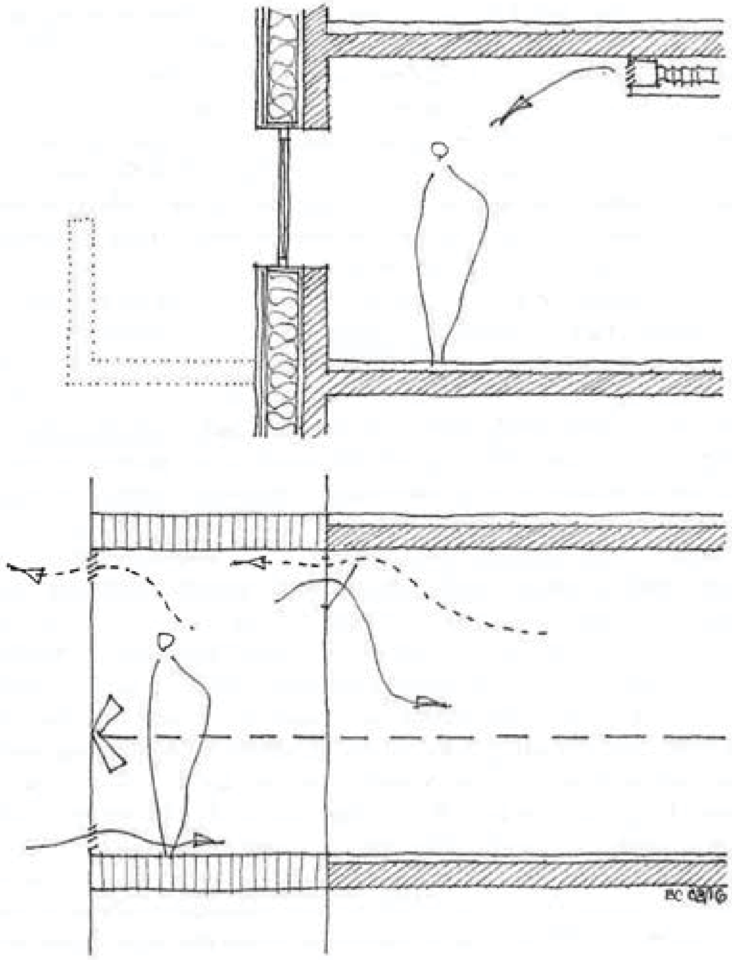

Figure 20.14 Façade concept, ARE study.
Source: Brian Cody

In a study carried out at an urban design scale for a large expansion of the university campus in Heidelberg, Germany, the objective was to investigate ways of arranging the given program of research facilities within the constraints of the 10-hectare site and find the most promising configurations in terms of energy performance. The study was carried out in advance of the competition process for the masterplan and the results, including guidelines with regard to optimal orientation, configuration, typology, etc., were made available to the teams partaking in the competition. Eight typological masterplan configurations were developed and their total energy performance – including potential building-integrated renewable energy production – was investigated in a dynamic simulation environment. Embodied energy demand and aspects such as the potential for creating effective spaces to facilitate informal communication and the effect on the local microclimate in the surrounding areas and on the existing campus were also considered. The goal of the study was to develop energy design parameters to guide and inform the subsequent masterplan design process. Among the typologies studied was a configuration employing atria both as communication spaces and as an energy design strategy. Using an optimized floor plan

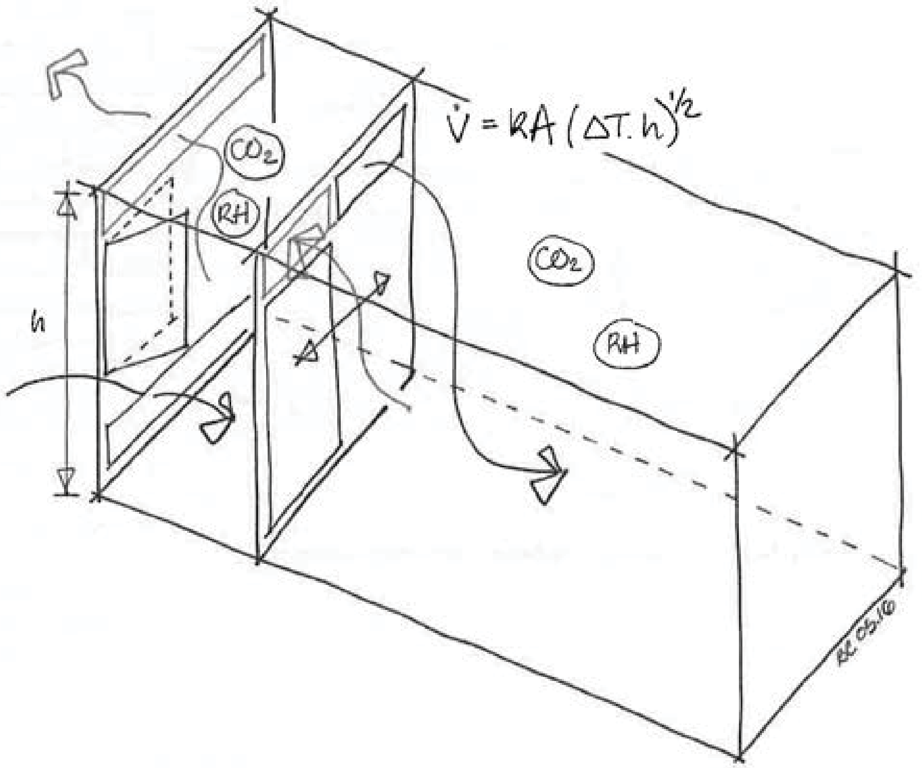

Figure 20.15 Natural ventilation concept, ARE study.
Source: Brian Cody

configuration, waste heat from the laboratories can be used passively (i.e. without the use of any active systems) to temper the unconditioned atrium and reduce the heat losses from the offices in winter (Figure 20.16).

The study showed that, based on the given site parameters, low-rise perimeter block-type configurations – with or without atria – had the highest performance, largely due to the increased solar energy production potential of the larger roof areas. A major concern of the study was related to the microclimate generated between the buildings and thus the experience of outdoor campus life the various typological approaches would foster.

In recent research at my institute we have been investigating "smart skins": façades which maximize energy performance by varying their properties to adapt to changing external and internal conditions. By continually selecting, mediating and modulating between inside and outside, such dynamic building skins can perform as a filter and play an important role in achieving desirable internal conditions within the sea of ever-changing conditions existing in the external climate. The proposed smart-skin concept incorporates and uses forecast data relating to future weather and likely user behavior (based on past experience and using an embedded artificial intelligence approach) as well as present-time data to decide the optimal configuration of physical properties and thus optimize performance (Figure 20.17).

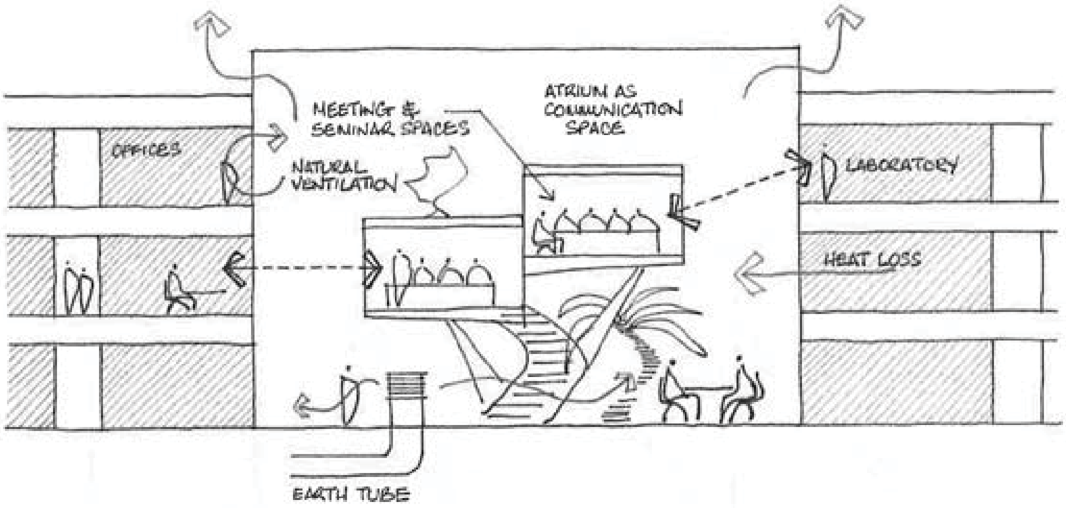

Figure 20.16 Atrium building typology, Heidelberg University Campus.
Source: Brian Cody

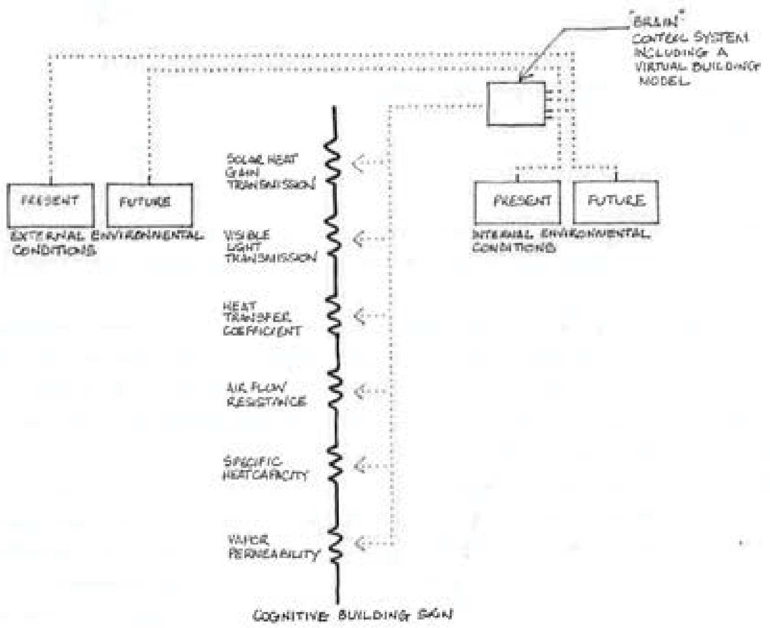

Figure 20.17 Smart façade concept.
Source: Brian Cody

The research carried out essentially involves the development of mathematical models which allow the potential energy performance to be simulated, and the optimal spectrum within which the building physics characteristics of the façade need to be varied to be determined, thus forming an important scientific basis for the development of a completely new approach to façade design. The models are complex, as a myriad of options for each parameter needs to be determined and compared for each time step. Then, as the simulation advances in time, the so-called "thermal history" associated with the processes needs to be recorded and integrated into the next time step (Cody et al., 2016). Presently we are investigating the incorporation of knowledge about the predicted short-term future into the model. Using weather forecasts and artificial intelligence algorithms, future external and internal conditions can be predicted. A by-no-means-trivial question the work throws up is the following: if we could accurately predict the short-term future in this way, would we be able to use that information to optimize the performance of façades in a significant manner? In any case, it does not take much imagination to imagine how such cognitive, sentient "smart skin" façades would impact on the sensory experience and phenomenology of the building spaces behind them.

Another research project at my institute is concerned with the energy aspects of "vertical farming" concepts. In the present-day food production system, food is grown on agricultural land outside the city and fossil fuels are used to manufacture the fertilizers and pesticides required to achieve the desired crop yields and to power the necessary agricultural machinery. After harvesting, the food stuffs are transported to facilities at other locations, where processing and packaging takes place, and are then distributed, finally arriving at retail outlets in towns and cities. For all of these processes, further energy use is required, today largely derived from fossil fuels. In the vertical farming concept, food production

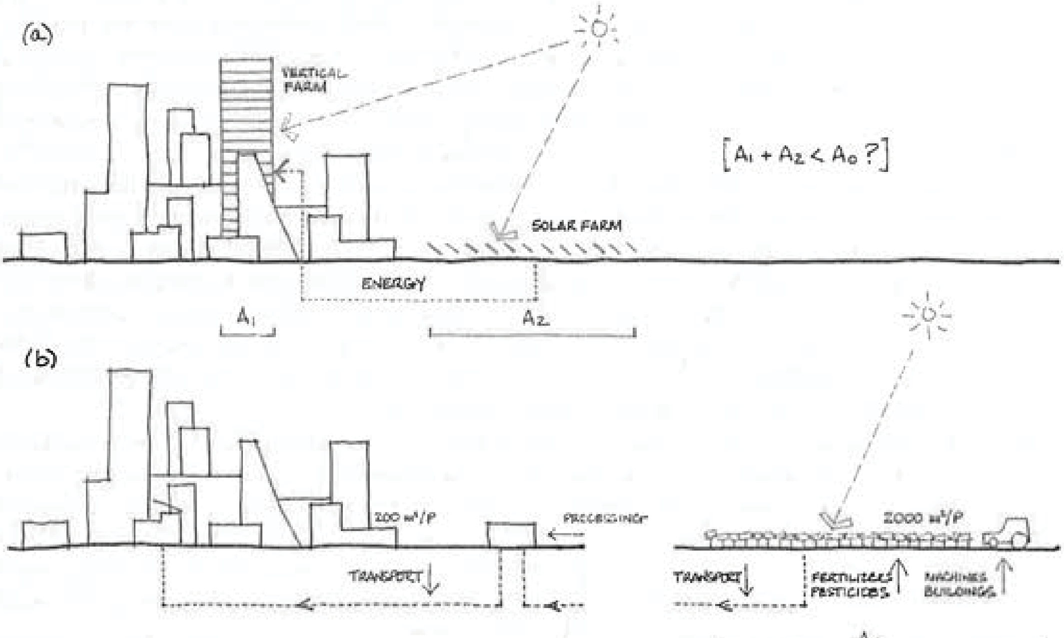

Figure 20.18 Vertical farming concept.
Source: Brian Cody

takes place in buildings with stacked levels on compact urban plots, significantly reducing land use for farming compared to the conventional system (Despommier, 2010). The energy demand, on the other hand, particularly for artificial lighting, is significantly larger and assuming that in the future this energy demand will have to be met by renewable sources, the land use for this becomes very significant owing to the low energy density of the sources. Therefore, the concept becomes viable if the total land area required, including the land required for the energy supply systems, is less than that required for conventional farming (Figure 20.18).

The potential of vertical farming thus depends strongly on the energy design strategies, and herein lies the focus of our research (Balasch et al., 2018; Podmirseg, 2016). A critical question is the impact on urban design and city life should this new typology be introduced on a large scale. This building type is essentially an industrial production facility with sparse human occupation and while these types of buildings have traditionally been located in the peripheral regions of cities, the whole premise of vertical farming is to locate the buildings in central urban areas, close to the human population, in order to reduce transportation energy demand. In addition to the obvious spatial implications for city planning and urban design, the implications for the working environment of the people employed in this radically new type of building will need to be considered.

The Virtual Dimension

The decision to employ movable walls on the low-energy building in Berlin described above, in order to allow solar energy to penetrate deeper into the apartments, obviously altered the spatial experience of the rooms too, allowing larger and smaller spaces to be created as needed. However, the users' experience of the building spaces was probably even more fundamentally affected by another energy design strategy. To foster a heightened awareness of the residents with regard to the effects of their behavior on the thermal behavior of the building and in order to strengthen their relationship with the building, a direct feedback loop in the form of a small visual display screen was included in each apartment, which provides information on the status of the various systems and the resulting energy consumption in real time. Measured data, collected during a monitoring period of two years after occupation, confirmed the effectiveness of this feedback loop on building performance (Senatsverwaltung, 2006). It should be noted that this was back in the 1990s before the widespread use of smart phones, etc. The information and communication technology available at the time was generally a lot more limited than at the present time. Today, there exists a vast – largely untapped – potential for the use of widely available technology to optimize communication between buildings and users and thus optimize energy performance. Considering all we have learned from fields such as behavioral economics in recent years, the possibilities for using a supplementary virtual environment to augment the physical one and contribute to increased performance via suitable interactions with the building's users is surely immense (Thaler, 2008). Of course, this digital/virtual environment also adds an additional dimension to the sensory experience.

Research work at my institute suggests that real progress in sustainable development cannot be achieved without a radical restructuring of the physical infrastructure of society. In the past twenty years we have created a new virtual environment with digital infrastructure, which, at least in theory, gives many working people unprecedented freedom with regard to the physical location where they carry out their work, basically allowing them to work almost anywhere. Today many people avail themselves of the possibilities offered up by these systems, in order to be more independent in both spatial and temporal terms. Nevertheless, we continue to design, construct and expand our cities and urban environments in essentially the same manner as was done a hundred years ago. In an interdisciplinary research project, we investigated the possibility of using this new virtual world to allow us to reconfigure our physical environment and infrastructure and in essence "rethink the city" (Figure 20.19).

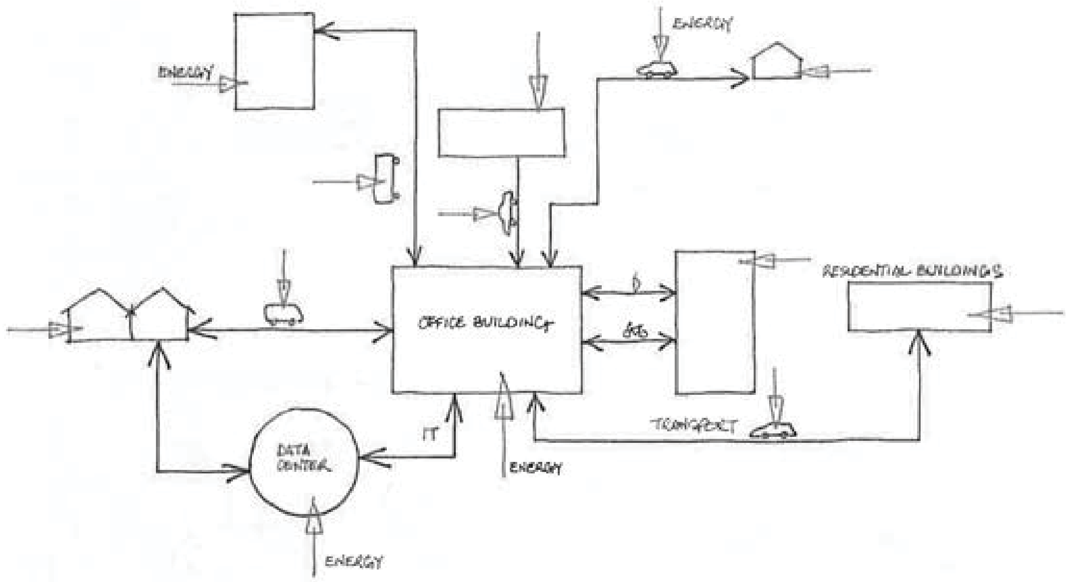

Figure 20.19 Rethinking the city.
Source: Brian Cody

By modelling the energetic structures of typical corporation and company structures, we showed that there is enormous potential to use new information and communication technologies to allow the generation of radically new forms of both building and transport systems, with the aim of increasing total energy efficiency. The results suggest an urban model with much smaller commercial office buildings than those we know today. These would become centers of face-to-face communication, while residential buildings would be configured to allow effective office work at home.

Building on these results, in further research work we studied more generally the consequences of more effective use of building space and the use of synergies between physical and virtual infrastructure, living and working spaces, teleworking, etc. In the search for strategies for spatial, temporal and virtual densification, a new typology, incorporating all the necessary infrastructural elements of society, including even industrial and agricultural uses, food production, energy generation, etc., was developed. In the cell-like structure of this so-called Hyper-Building-City model, each cell has the ability to work independently and function in a self-sufficient manner. However, when linked together, they mutually assist each other so that the whole is more than the sum of the parts (Figure 20.20).

The Hyper Building itself is a structure which allows a population density roughly equal to that of Manhattan, needs no external energy supply and no external water supply, produces no waste, emits no CO2 emissions and needs little or no external food supply. Vertically distributed spaces for residential, office and industrial use are provided alongside parks and areas for agriculture, biomass and energy production. Linked together, they form a three-dimensional urban structure, combining urbanity and nature, density and diversity. A central feature of the conceptual approach is the synergetic integration of the different systems and the exploitation of symbiotic relationships between nature, man and technology. Plants supply oxygen for humans. Humans supply CO2 for plants. Biological waste is used as fertilizer. Waste heat is reused, and water recycled. The implications for the spatial experience of buildings and cities – should these concepts, which are largely driven by energy design considerations, be even partly

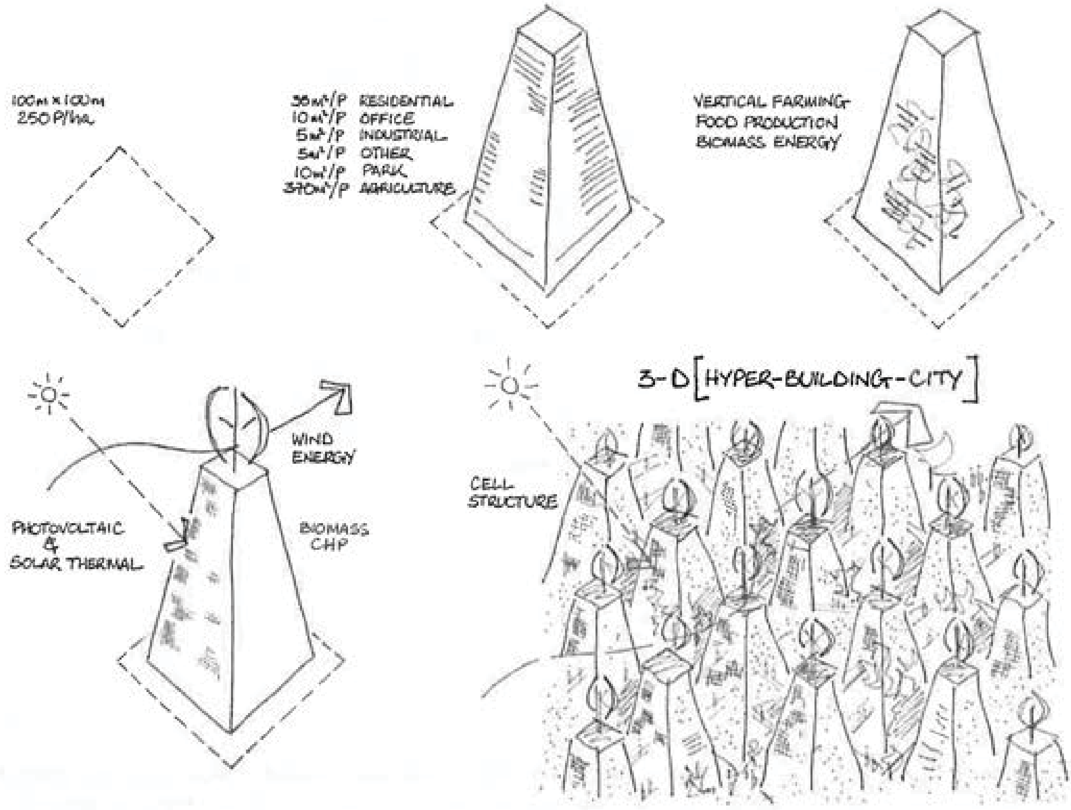

Figure 20.20 Hyper-Building-City.
Source: Brian Cody

implemented – are clearly enormous. In any event, it seems evident that the solution to one of the most central problems of our time, namely that of energy supply in a world with limited resources, will inevitably affect the form of the built environment and its phenomenology in a significant manner

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