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Prevalence and Evaluation of Bioclimatic Design Techniques used to achieve Low Energy Comfort in Architectural Design Proposals

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Abstract

This paper analyses responses of ninety-nine students to a design brief for a public building in different regions of China. The research determined the level of understanding and skills development in students who will be the next generation of building designers, procurers and developers. The students were asked to design in a bioclimatic fashion and therefore to consider the building to be as free running as possible, and thus supportive of adaptive comfort principles. The designed solutions were then analysed to determine: the types of bioclimatic technique chosen to be employed; the actual prevalence of use of the techniques in each case; and the successful implementation within the schemes. The results identify barriers to application in design and define productive areas of future comfort research including analysis of interactions between techniques, and the optimisation of whole building solutions. The adoption of bioclimatic design techniques is complementary to adaptive approaches to thermal comfort and reductions in energy use in buildings.

Keywords: bioclimatic design; comfort; climate; students; China

1 Introduction

In order to make substantial reductions in energy consumption by buildings there is a need to encourage two changes to current processes and systems. Firstly, building occupants need to be provided with, and made aware of, the potential to use techniques such as adjustment of their clothing, movement of their position/location within a building space, and control of low or zero energy use systems to modify the internal environment. All these features enable occupants to make optimal use of the thermal conditions available within a building. Secondly, architects and others need to design buildings to match closely with the external climate within which they are situated, and to encompass features that allow occupants to modify the building, and also for it to be robust and adaptable to future climate change. This paper specifically addresses the knowledge needed by designers to achieve the second of these requirements. A further stage of research can also be considered in which the positive and negative interactions between different techniques and technologies in practice should be evaluated holistically in order to understand how to produce an optimised whole-system building outcome.

The method of the research was to issue postgraduate students from a variety of first degrees, but who were working together on an environmental design course, with a brief to design a bioclimatic building. The project brief required the design of a public information/resources centre set in one of ten different Chinese cities; each with a different climate and therefore each with a different set of constraints. Each student worked collaboratively in forming ideas for solutions for a particular city but ultimately submitted an individual project. Shared precedent case studies were utilised to inform the design process. This paper describes the background to the project and process of analysis of the outcomes and resulting implications for approaches to design education.

2. Building Design and Energy Codes in China

The rapid urbanisation and associated construction development that has taken place in China in recent decades has the potential to cause large increases in building energy consumption. This can arise from three main causes:

- Expectations amongst those moving into newer properties, for higher standards of comfort which are normally associated with intensive heating, ventilating and air conditioning systems.
- A disregard for older, more traditional design techniques both linked to the past and also unable to meet modern needs.
- Building design regulations which impact on certain characteristics of design but which do not exploit the potential for more adaptive approaches and which demand an
- understanding of bioclimatic design.

A number of codes have been developed over the years for China (for instance Ministry of Construction, 1993), but the size of the country and the complexity of the climate zoning has given rise to difficulties. Seven main zones (or partitions) have generally been identified in the literature, and with each 'partition' having several subdivisions. These are listed below.

1. Partition I: Cold regions type 1 (4 climate divisions). January average temperature ≤ -10 ºC; July average temperature ≤ 25 ºC.
2. Partition II: Cold Regions type 2 (2 climate divisions). January average temperature of -10-0 ºC; July average temperature of 18-28 ºC.
3. Partition III: Hot summer and cold winter area (3 climate divisions). January average temperature of 0-10 ºC; July average temperature of 25-30 ºC.
4. Partition IV: Sub-tropical region (2 climate divisions). January average temperature> 10 ºC; July average temperature of 25-29 ºC.
5. Partition V: Temperate regions (2 climate divisions). January average temperature of 0-13 ºC; July average temperature of 18-25 ºC.
6. Partition VII: Cold regions type 1 (2 climate divisions) + Cold regions type 2 (1 climate division). January average temperature of 0 - 22 ºC; July average temperature <18 ºC.
7. Partition VII: Cold regions type 1 (3 climate divisions) + Cold regions type 2 (1 climate division). January average temperature of -5 - 20 ºC; July average temperature ≥ 18 ºC; July average relative humidity <50%.

A discussion paper by Chmutina (2010) identified improvements in codes that had taken place over a number of years but also identified some of the barriers, one of which was a more general understanding of the methods by which energy efficiency in buildings could be improved. The International Energy Agency has reported an increase in the enforcement of building energy codes in China in recent years (IEA, 2013); and a recent online report of work at the Joint Global Change Research Institute (Clickgreen, 2014) suggested substantial savings could be made in a straightforward manner from basic improvements to building regulations.

An approach based solely on upgrading and enforcement of building regulations does not however deal with an underlying problem. Often building regulations result in simplified impacts, such as increases in thermal insulation standards, or changes to the specifications of heating and cooling systems used. A greater potential is to impact on building designers in ways that do not imply technical fixes as the optimum solution, but through changes to design practices that result in better initial buildings; buildings suited to the climate. In this paper it is the last of the three bullet points identified above which is being addressed; in other words, how to improve knowledge and application of bioclimatic design.

The argument advanced in this paper therefore is that if architects and building designers can be given the skills and understanding to enact design techniques in keeping with the needs of the specified climate, the requirement for energy intensive heating and cooling systems is reduced. However in the particular situation of China there are additional complexities in terms of breadth of knowledge and experience required as well as in dealing with a variety of climate types. The research has therefore been carried out to understand better how the building designers of the future currently perceive the opportunities for climate sensitive design and how they enact it. It seeks to discover whether the designers understand climatic classifications; whether they can select appropriate techniques; whether they choose to apply those techniques; and whether the application is fully successful.

3. Bioclimatic Design Techniques

A number of authors over a period of time have both identified the key building bioclimatic design techniques, and also refined them. The Olgyay brothers, Victor and Aladar, in their seminal work 'Design with Climate' (Olgyay and Olgyay, 1963) set in motion design techniques which are still valid in modern architecture. Baruch Givoni in several works ordered the principles and developed algorithms to aid in application (Givoni, 1969, and Givoni, 1998), and Szokolay carried on with this approach to produce yet more organised calculation techniques (Szokolay, 2008).

In all of these works the key parameter was the understanding that it is the combined effect of a number of environmental parameters that affects a person's sense of comfort and that the design of the building itself can enhance or reduce (depending on need) the impact of these parameters. The implications for thermal comfort and energy use are that if more successful utilisation can be encouraged adaptation opportunities are maximised.

Some of the authors identified above have expended efforts to allow visualisation of the impacts of bioclimatic design through the medium of overlays of climate and building information onto psychrometric charts. The resulting diagrams are known as building bioclimatic charts and have both visual appeal as well as underlying analytical value for designers who think through the visual medium.

All of the techniques which follow have been identified as bioclimatic design opportunities; all have been previously well researched and documented, hence below only a brief introduction to each is provided.

3.1 Solar shading

The simplest form of bioclimatic design technique is to provide suitable shading from the excessive heat gain from the sun. In application in design this technique, although simple, must be used with care, particularly where there is a need in winter to allow clear and unobstructed admission of sunlight to counteract the cooler temperatures. In effect its use must be balanced against passive solar heat gain techniques in a calculated way. Many design projects incorporate solar shading, however they can do so in an unsuitable way, and the onus is on the designer to show how shading systems will operate. In more modern architecture there are opportunities to incorporate such technologies as photovoltaics (PV) into shading devices. In some climates the shading devices may also be used to control wind driven airflows around a building façade.

3.2 Thermal mass

Thermal mass techniques exploit the themo-physical properties of building materials to absorb and retain heat through the thermal capacity of the material and amount and placement of that material. The combination of capacity and physical amount gives rise to the slightly unscientific term 'thermal mass'. Thermal mass provides inertia and impacts on energy flows through the more massive components of the building structure; time-lags for heat flows and reductions in temperature swings are typical outcomes of its use. Thermal mass techniques can also be used in conjunction with ventilation options such as night-time purging which uses cooler air overnight to pre-cool building components ready for the warmth of the following day. In the analysis presented later in the paper these two aspects have been decoupled to avoid confusion with application of ventilation techniques on their own.

3.3 Passive solar design

Passive solar design is a well-known and oft-exploited technique used in building design. Conventionally the term applies to the arrangement of windows and other solar absorbing devices such as trombe walls. The simple act of placing windows on a particular façade of a building may indicate a designer seeks the benefits of passive solar design, however for successful implementation careful calculation is also required to ensure overheating either does not occur or is mitigated. Careful use is also required to demonstrate the benefits will be felt at the appropriate time of day for the building type and occupation schedule. It is also a technique which is often incorporated almost without thinking, and which therefore needs to be specifically acknowledged by the designer.

3.4 Natural ventilation

Ventilation of buildings provides simple and effective means of transferring heat between the internal and exterior environment, or vice-versa. Although the thermal capacity of air is small, the volumes of air that can sometimes be induced to move, and the convective impacts of increased air flows (both on humans and on building surfaces), means there is great potential to affect comfort and energy use. Almost all buildings have the potential to use natural ventilation through the opening of suitably placed windows and ventilators. Fully air conditioned buildings are perhaps the only category to actively seek to exclude such ventilation for fear of undermining the operation of the heating, ventilating and air conditioning systems. Natural ventilation is also the theme of investigation in many research projects associated with applying adaptive principles in thermal comfort studies. More summative detail can be found in Nicol et al (2012). Since windows and other openings can be introduced into almost any building, it is the correct placement and functioning of such openings which must be designed with care to enhance natural ventilation potential. Many architectural projects, both by students and from professionals, include the promise of natural ventilation justified by the placement of arrows on sectional and plan drawings. These 'hopeful arrows' are often insufficiently supported by calculation and analysis, and therefore can disappoint clients and occupants when expected airflows fail to materialise post- construction. In summary a powerful option, but one that must be shown to operate as required.

3.5 Evaporative cooling

In climates and building situations where the humidity of the air is low but found in conjunction with high ambient temperatures, the evaporation of water into the air has the impact of lowering its temperature. This process can be used directly (where water is evaporated directly into the air entering or already inside a building); or indirectly where the evaporation takes places to cool an intermediate component (which can take a variety of forms). These are techniques which many modern day building designers have little or no direct experience of, and therefore when suggested for incorporation into design will require some preparation. Simple versions such as provision of fountains or bodies of water close to, or inside, a building, can easily be utilised but there is little to guide the designer on the final impact. The impacts of more sophisticated systems are more easily determined but there can be a reluctance to employ them due to lack of detailed understanding.

3.6 Other techniques

In addition to the five basic techniques listed above, there are many other associated options or options which extend the impact of those listed. Though adequate insulation of a building envelope should be straightforward to achieve there are examples of very high levels known as such ‘superinsulation’. Another set of techniques is associated with wind protection: this can take several forms such as the partial or full burial of the building in the ground (earth berming), or the provision of external screening using natural or artificial means to achieve wind protection. There are also many varieties of glazing systems incorporating special products or techniques which give greater bioclimatic control. Finally there are numerous hybrid systems which employ both passive and active components to achieve optimum environmental control.

In the analysis which follows later in the paper, the prevalence and use of these techniques is considered.

4. Climate and Cities

China has a more complicated climatic system than many other countries both because of its size and also because of the nature of a significant central area which experiences both hot summers and cold winters. In general climatic design has to deal with more than one significant feature, making the task for architects and other building designers more difficult than in a number of other countries.

Ten cities were used in all in the project which has run so far over two years; brief details of each follow including very basic climatic information.

Beijing is the capital of China located in the northeast of the country. It has a dry, monsoon-influenced humid continental climate characterized by hot, humid summers due to the East Asian monsoon. Winters are generally cold, windy, and dry. Spring may experience sandstorms from the Mongolian steppe, accompanied by rapidly warming, but generally dry, conditions. Autumn, like spring, sees little rain, but is crisp and short. The monthly daily average temperature in January is −3.7°C; in July it is 26.2°C. Precipitation averages 570 mm annually, 75% falling from June to August

Guangzhou is located in the southwest of the country close to Hong Kong. It is just south of the Tropic of Cancer, and experiences a humid subtropical climate influenced by the East Asian monsoon. Summers are wet with high temperatures, high humidities and a high heat stress index. Winters are mild and relatively dry. There is a long monsoon season, from April to September. Monthly average temperatures vary from 13.6°C in January to 28.6°C in July. Annual rainfall is over 1,700 mm.

Harbin is located in the far northeast of the country. It has a monsoon-influenced, humid continental climate. The city is known for its cold weather and long winter which is dry combined with very low temperatures (average temperature in January of −18.4°C), which is accompanied by significant sunshine. Spring and autumn are transition periods. Summers can be hot, with a July mean temperature of 23°C and much rainfall with over 500 mm falling in July and August.

Kunming is located in the southwest of the country. It has an elevation 1,900 metres and experiences one of the mildest climates in China, with short, cool dry winters, and long, warm and humid summers. The city has a subtropical highland climate; average temperatures range from 8.1°C in January to 19.9°C in June. The rainy season is May to October; the rest of the year being dry. Rainfall averages 1000 mm, 60% of this falling from June to August.

Lhasa is located in the far west of the country. It has a cool semi-arid climate due to its height above sea level. It experiences cold winters and mild summers, but is somewhat protected from extremes by its valley location. It gets 3,000 hours of sunlight each year. The coldest month is January with an average temperature of −1.6°C and the warmest month is June with a daily average of 16.0°C. Rainfall averages 430 mm; most rain falls in July, August and September.

Sanya is located in the far south of the country. It lies at the southern end of Hainan Island and is the second most southerly city in China. The area has a tropical wet and dry climate with very warm weather all year. The Monsoon is strong, with long wet season but with a significant dry season. The coolest month is January, averaging 21.6°C; the hottest is June, averaging 28.8°C.

Shanghai is located towards the middle of the east coast of the country. It has a humid subtropical climate with four distinct seasons. Winters are cold and damp, with northwesterly winds from Siberia causing nighttime temperatures to drop below freezing. Summers are hot and humid, with an average of 8.7 days exceeding 35°C annually. The city may experience typhoons in summer and the beginning of autumn. The most pleasant seasons are spring (although changeable and often rainy), and autumn (which is generally sunny and dry). Temperatures average 4.2°C in January and 27.9°C in July.

Urumqi is located in the far northwest of the country. It has a semi-arid climate with large differences between summer and winter. The July average temperature is 23.7°C whilst in January the average is −12.6°C. The city is semi-arid, with its summers slightly wetter than its winters. The annual rainfall averages 290 mm.

Wuhan is located in the middle south of the country in a particularly difficult area with hot summer combined with cool winters. It experiences a humid subtropical climate with significant rainfall and four distinct seasons. The city has oppressively humid summers. Spring and autumn are generally mild, while winter is cool with occasional snow. The average temperature ranges from 3.7°C in January to 28.7°C in July. Annual rainfall averages about 1,270 mm falling mainly between May and July.

Xi'an is located in central China a little towards the north. It experiences a temperate climate influenced by the East Asian monsoon, classified on the border between a semi-arid climate and a humid subtropical climate. It has hot, humid summers, cold, dry winters, and dry springs and autumns. Most of the annual rainfall occurs between July and October. Dust storms can occur during March and April. Summer months have frequent but short thunderstorms. The average temperature ranges from 0 °C in January to 26.6 °C in July, with an annual mean of 13.7 °C.

5. Design Brief and Project

The vehicle for research used in this investigation was to provide a group of students with basic information on climate and bioclimatic design techniques, and then to examine the results of their labours in the production of responses to a design brief. The assignment stated:

"This assignment will provide you with the opportunity to apply bioclimatic design principles to the design of a small institutional building located in a particular climatic zone of China. The goal is to produce a design report which illustrates the appropriate application of bioclimatic design principles for a particular climatic type (e.g., hot-humid, severe cold, continental, etc) and for a particular latitude (which will influence such things as sun angle)…. The intention is that you explore what might be practical solutions to the provision of a good quality environment while minimising the use of heating, ventilating, and air conditioning equipment (that is otherwise both capital intensive and expensive to run). …The brief is for a small community information resources centre (which could include some library facilities)."

Students were assigned to work on one of ten different cities (these have already been identified in section 4 above). As a result of the project ninety-nine students submitted work spread over two academic years. The breakdown of submissions was as follows: Beijing (12 proposals); Guangzhou (12 proposals); Harbin (5 proposals); Kunming (6 proposals); Lhasa (12 proposals); Sanya (12 proposals); Shanghai (12 proposals); Urumqi (6 proposals); Wuhan (11 proposals); and Xi'an (11 proposals).

In each year the design project ran over an intensive period of tuition (nine days) but with preparation time beforehand and a period of approximately four weeks afterwards during which time students refined and produced their design proposals.

Students were allowed and indeed encouraged to make use of analytical techniques some of which used computer based information to determine the optimum bioclimatic features and design principles to utilise. Some of the technology permitted analysis which should have led to direct specification of the technologies and techniques most appropriate to the site and climate. Whilst all students had some access to such information some exploited it better than others and hence a range of outcomes and degrees of success, at least in bioclimatic terms, could be identified. It should be stated that not all of the most well-designed bioclimatic buildings were as successful as architectural spaces, or in terms of aesthetics, or as complete designed solutions.

6. Analysis of Projects

Each one of the ninety-nine submissions was analysed to collect information on the use of the bioclimatic design opportunities. Success or otherwise in the use and application of any single technique on its own is no indicator for the overall success of a design scheme, and indeed some submissions that were strong in one area proved to be weaker in others. In the analysis which follows there is no attempt to grade the projects, simply to analyse use of techniques.

The following list provides the headings under which each scheme was judged.

- Successful completion of a full climate analysis.
- Successful and clear identification of the climatic classification.
- Identification separately and specifically of each of the following techniques as being suitable for use in the assigned climatic location: solar shading; thermal mass; passive solar design; natural ventilation; evaporative cooling; other non-specific techniques.
- Use of each of the specified techniques within the design proposal, either clearly identified or implicitly as a consequence of design decisions taken (that is, in some cases the students did not specifically describe incorporation of the technique, but nevertheless it was present): solar shading; thermal mass; passive solar design; natural ventilation; evaporative cooling; other non-specific techniques.
- Analysis of those techniques used in the design proposal (that is under the same headings which follow) to assess whether each was described and documented in sufficient detail to give confidence in a successful outcome: solar shading; thermal mass; passive solar design; natural ventilation; evaporative cooling; other non-specific techniques.
- Evaluation in each case where a technique had been identified from the climatic analysis as to whether it had been employed in the design.
- Evaluation in each case where a technique had been employed in the design to determine whether it had been used successfully: that is, was it described and documented in sufficient detail to give confidence in a successful outcome.

The data for each of these assessments for each scheme were then considered on a city by city basis and overall.

7. Results

The results of the accumulation of analyses can best be documented in the form of tables. Each table gives the data in summary form for each city/climatic location; and then collectively in the final row. It should be remembered that some of the cities had more submitted schemes than others.

In the first (Table 1), the data relating to the successful climate analysis and then classification of the climate (which should then have made determination of the range of bioclimatic options clearer) are shown.

Table 1: Success of climate analysis and classification

City	Proportion completing full climate analysis	Proportion correctly identifying full climate classification
Beijing	67%	58%
Guangzhou	75%	67%
Harbin	80%	60%
Kunming	83%	100%
Lhasa	67%	42%
Sanya	42%	42%
Shanghai	67%	75%
Urumqi	50%	17%
Wuhan	91%	82%
Xi’an	82%	73%
Overall average	70%	62%

It is clear that even with support not every student was able to complete a full climate analysis. In part this may have resulted from the page limit applied to the report size and in part it resulted from a lack of detail in the easily obtainable climate information: for instance for the remote city of Urumqi data were more difficult to acquire. For the determination of the climate classification, errors may omissions reflect the difficulty in some complex cases of classifying the climate exactly. One can also observe that in some cases even if the analysis was incomplete, the classification was determined correctly.

In table 2 the data show the frequencies of identification of techniques to be used directly from the climate analysis. Clearly not all techniques are applicable in all locations, but if the processes had been carried equally by all, one would expect a polarisation in results showing either acceptance or rejection for each city. This happens in some but not all cases.

Table 2: Bioclimatic design techniques identified from the climate analysis

City	Proportion of proposals selecting specified bioclimatic design technique identified for use from climate analysis performed					
	Solar shading	Thermal mass	Passive solar design	Natural ventilation	Evaporative cooling	Other techniques
Beijing	50%	33%	92%	100%	42%	50%
Guangzhou	58%	25%	17%	100%	25%	17%
Harbin	0%	40%	100%	100%	0%	60%
Kunming	17%	50%	83%	83%	0%	0%
Lhasa	33%	33%	83%	17%	17%	42%
Sanya	17%	8%	8%	92%	0%	17%
Shanghai	0%	17%	42%	92%	25%	8%
Urumqi	17%	33%	83%	33%	17%	67%
Wuhan	0%	100%	73%	100%	0%	0%
Xi'an	0%	73%	100%	91%	45%	0%
Overall average	21%	40%	64%	82%	19%	23%

In table 3 the data showing the actual use/incorporation of the technique into the design are provided. Assuming students obtained results from the climate classification correctly then this should show a direct translation into use from table 2. Though there are a number of similarities there are also clear discrepancies: in some cases techniques are used which were not selected and in others selected techniques are then ignored. This shows a degree of inconsistency and is perhaps something that is linked to how the architectural design progressed, and circumstances in which students for other reasons chose to reject a particular design option, or perhaps to include another. It may also show that some techniques are easier to incorporate, and that the students, as with other designers, chose those techniques they could understand and utilise within a restricted period of time. Note the data represent inclusion not success which is covered in the next table

In table 4 the analysis moves to identify those design techniques which could be explicitly identified as having been implemented successfully. In this case success was not judged by any architectural scale but rather by the provision of sufficient information, drawn, written and calculated, such that confidence might be placed in the design to deliver its intention. As with all such proposals, the actual outcome can only be judged when a building is completed and occupied, however the analysis here is the best proxy available. The table is a little misleading since it shows the overall percentage of successful implementations, when in some cases only a few were attempted, hence the low percentage for evaporative cooling and 'others' categories. Interestingly however, natural ventilation, whilst being both the most frequently identified technique in tables 2 and 3, fails to deliver at the same level in terms of successful implementation.

Table 3: Bioclimatic design techniques utilised in projects in each city/climate

City	Proportion of proposals incorporating specified bioclimatic design technique into building design proposal					
	Solar shading	Thermal mass	Passive solar design	Natural ventilation	Evaporative cooling	Other techniques
Beijing	75%	17%	92%	92%	8%	50%
Guangzhou	100%	0%	0%	100%	0%	0%
Harbin	0%	80%	100%	100%	0%	60%
Kunming	50%	33%	100%	83%	0%	0%
Lhasa	58%	33%	100%	25%	0%	50%
Sanya	75%	0%	0%	100%	0%	17%
Shanghai	58%	0%	25%	100%	33%	0%
Urumqi	17%	17%	100%	0%	0%	50%
Wuhan	100%	45%	82%	45%	0%	0%
Xi'an	18%	73%	91%	55%	0%	0%
Overall average	62%	26%	63%	72%	5%	20%

Table 4: Bioclimatic design techniques successfully incorporated into designs for each city.

City	Proportion of proposals with specified bioclimatic design technique that were successfully deployed and explained within building design proposal					
	Solar shading	Thermal mass	Passive solar design	Natural ventilation	Evaporative cooling	Other techniques
Beijing	67%	8%	92%	42%	25%	8%
Guangzhou	50%	0%	0%	83%	0%	0%
Harbin	0%	80%	100%	80%	0%	60%
Kunming	50%	50%	67%	50%	0%	0%
Lhasa	50%	42%	100%	8%	0%	33%
Sanya	75%	0%	0%	67%	0%	17%
Shanghai	58%	0%	17%	100%	8%	0%
Urumqi	17%	17%	100%	0%	0%	50%
Wuhan	82%	9%	91%	36%	0%	0%
Xi'an	18%	64%	91%	45%	0%	0%
Overall average	52%	22%	61%	53%	4%	13%

In order to identify issues for discussion and potentially further research, the data for each project were further analysed to consider on a city by city basis if there were specific fault lines. Table 5 attempts to show where either techniques were not identified, but were included anyway by the students, or where identified techniques were not incorporated. The threshold levels applied were 20% of projects in each city. The increased use of solar shading can provide benefits however this seems to be happening by accident rather than choice. Missing use of evaporative cooling is perhaps to be expected as it is a technique less well known to the students and less well documented, however it perhaps also indicates a need for reinforcement in terms of understanding. The omission of thermal mass and natural ventilation in use however could lead to problems of achieving desired bioclimatic outcomes, the more so because the techniques are generally well-known and utilised.

In Table 6, the data are collated to identify cities where particular anomalies seemed to be occurring, that is when a technique was included but not successfully implemented (according to the definition applied above). From this summary data it seems that two techniques in particular should be analysed in more detail and with follow up to examine impacts but for rather different reasons. The first is the use of solar shading and the second the use of natural ventilation.

Table 5: Evaluations of bioclimatic techniques identified but not used or used but not identified

City	Evaluation of issues: √ = techniques not identified but incorporated anyway X = technique identified but not incorporated					
	Solar shading	Thermal mass	Passive solar design	Natural ventilation	Evaporative cooling	Other techniques
Beijing	√				X	
Guangzhou	√	X				
Harbin		√				
Kunming	√	X				
Lhasa	√			√ and X		
Sanya	√					
Shanghai	√				√ and X	
Urumqi				X		
Wuhan	√	X		X		
Xi’an		√ and X		X	X	
Overall	√	X		X	X	

Table 6: Unsuccessful implementation of bioclimatic design techniques

City	Evaluation of issues: X = technique incorporated into design but not fully successful in implementation in design					
	Solar shading	Thermal mass	Passive solar design	Natural ventilation	Evaporative cooling	Other techniques
Beijing				X	X	X
Guangzhou	X			X		
Harbin						
Kunming	X		X	X		
Lhasa						
Sanya					X	
Shanghai						X
Urumqi						
Wuhan	X	X				
Xi’an						
Overall	X			X		

8. Conclusions

The information presented in this paper and therefore the conclusions which can be drawn all relate to student project work rather than professional building designs. Nevertheless such students are the practitioners of tomorrow and it is important they are able to understand climatic analysis and the appropriate choices of building bioclimatic design techniques.

The following summary conclusions may be drawn:

- Designers who have access to a wide variety of climate information need further guidance to ensure correct assessment of classification of climate and thus are enabled to make appropriate selection of bioclimatic design techniques.
- Designers should be encouraged to document choices available and reasons for selection or rejection of a technique in a particular situation.
- Accidental inclusion or exclusion of a technique needs to be explained both to avoid use of inappropriate options for design, and to ensure all the necessary techniques are included as an expectation in a design proposal.
- Bioclimatic design techniques are known by most designers but the detail of their functional operation needs to be better communicated, particularly for some of the less well known options or those where there maybe conflicts between techniques.
- Designers should be encouraged at the end of the design process to compare outcomes with expectations of use, and to justify reasons for variation.
- The particular aspects of bioclimatic design that deserve attention are as follows:
  - use of solar shading should not be a by-product but something explicitly designed;
  - thermal mass techniques are often considered but then become lost in the architecture of the design – this should be avoided;
  - natural ventilation is often assumed to be taking place but the means for it to happen need to be more calculated and determined to be classed as successful;
  - designers who specify evaporative cooling need to understand the processes more clearly.

In completing the analysis it is also clear that a further stage of research and student interaction has potential to improve outcomes – that is a reflective analysis stage on completion of the design. At this point it would be possible to engage with analysis of positive reinforcement or negative interactions occurring between the climate and the chosen techniques and between adopted techniques themselves. This could also then be used to optimise overall building performance.

The use of bioclimatic design techniques is increasing in popularity and can open up opportunities for more adaptive approaches to create thermal comfort in more naturally conditioned buildings. In order to achieve this however, designers need to be equipped with more detailed understanding and skills so as to avoid unfulfilled expectations. There is much optimism for the future given the potential displayed in the project analysed for this research, but even more effort is required to complete the task.

References

Chmutina, K. 2010. *Building Energy Consumption and its Regulations in China*, Discussion paper 67, China Policy Institute, The University of Nottingham, UK.

Clickgreen, 2014. China could cut energy use by 22% through efficient building plans. Available online at http://www.clickgreen.org.uk/research/trends/124152-china-could-cut-energy-use-by-22-through-efficient-building.html [accessed 30 January 2014]

Givoni, B. 1969. *Man, Climate and Architecture*, Elsevier Press.

Givoni, B. 1998. *Climate Considerations in Building and Urban Design*, John Wiley & Sons.

IEA, 2013. *Modernising Building Energy Codes*, International Energy Agency

Ministry of Construction, 1993. *National Standard: Building climate zoning standards – Standard of Climatic Regionalization for Architecture*, GB 50178-93, State Bureau of Technical Supervision/ Ministry of Construction.

Nicol, F.; Humphreys, M.; Roaf, S. 2012. *Adaptive Thermal Comfort: Principles and Practice*; Routledge: Abingdon, UK.

Olgyay, V. and Olgyay, A. 1963. *Design with Climate*, Princeton University Press. Szokolay, S. 2008. *Introduction to Architectural Science*, Routledge, 2nd Edition.