AN INVESTIGATION ON THE AGE-BASED THERMAL ENERGY BALANCE OF OCCUPIED CLASSROOMS IN PRIMARY SCHOOLS

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ABSTRACT

AN INVESTIGATION INTO THE AGE-BASED THERMAL ENERGY BALANCE OF OCCUPIED CLASSROOMS IN PRIMARY SCHOOLS

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The effect of indoor heat gain from occupants as a bio-thermal source was hypothetically assessed in terms of its contribution to overall heating requirements during such occupancy and hence to potential energy savings. The spaces considered were classrooms in a sample of 6 public co-educational primary schools located within the city limits of Ankara built after 1998, the date when compulsory primary education was integrated to encompass grades 1 through 8 for ages 6 to 14, respectively. Being so, this allowed distinguishing disparities among age groups on the basis of classroom density and body surface area. Data for both were obtained from existing sources. As norms for the latter essentially pertained to adult populations, pertinent corrections were made for each of the age groups in question as well as for gender. Additional adjustments were made on the basis of the literature in order to integrate data on local weather conditions into heat balance equations. Energy requirements for heating were calculated according current Turkish standards.

Results based on extensive comparisons using Student's *t*-test confirmed that there were significant differences between grades in terms of supplementary heating requirements. These differences were not, however, large enough to warrant any meaningful intervention with regard to such design aspects as window orientation, exterior wall composition and/or indoor temperature level.

Keywords: thermal exchange/comfort/load; classroom heating; thermal body emissions

ÖZ

İLKÖĞRETİM OKULLARINDAKİ YAŞ PROFİLİNE GÖRE SINIFLARIN ISIL ENERJİ DENGESİ ÜZERİNE BİR ARAŞTIRMA

Taner, Özün

Yüksek Lisans, Mimarlık Bölümü,
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Kuramsal bir öngörü üzerine kurgulanan bu çalışma, kapalı hacimlerde bulunan insanları; ortama yaydıkları bedensel ısı bakımından bu hacimlerin ısıtılmasına ek birer kaynak olarak kabul etmekle ne denli bir enerji tasarrufu sağlanabilineceğini belirleyebilmek üzere ele alınmıştır. Çalışma alanı olarak ilköğretim okul yapıları belirlenmiş; araştırmanın kendisi ise Ankara il sınırları içinde 1998 sonrası 8 yıllık zorunlu ilköğretime geçişle, devlet okulu olarak inşa edilmiş ilköğretim yapıları arsından seçilen 6 örnek üzerinde yürütülmüştür. Seçilen bu yapı türü, 6–14 yaşları arasında olmalarından ötürü hem çok değişken beden yapısı, hem de bulundukları ısıl ortam koşullarına çok duyarlılık gösteren bir nüfusu oldukça kalabalık 8 ayrı sınıfta barındırmakla; bu nüfusun beden ölçüleri bakımından farklılaştırılmasını mümkün kılmıştır. Kullanılan veri ve hesap yöntemleri, konu yaş gurubu bakımından gerekli bazı düzeltmelerle literatürden alınmış; böylece elde edilen sayısal sonuçların istatistik önem taşıyıp taşımadıkları araştırılmıştır. Sınıf nüfuslarınca ortama yapılan ısıl etki ile birlikte konu sınıflara özgü ısı yükü hesaplarında ise yürürlükteki Türk Standartları tarafından ortaya konan yöntem kullanılmıştır.

İkili *t*-sınaması (*t*-testi) ile yapılan karşılaştırmalar, sınıflar arasında ısıtma enerjisi gereksinimleri bakımından önemli farklılıklar olduğunu göstermekle birlikte bu farklılıklar, sözkonusu sınıfların pencere yönelimleri, dış duvar malzeme katmanları ve iç sıcaklık

düzeyleri gibi tasarım unsurlarında yapılacak müdahalelerle ele gelir herhangi bir iyileştirme yaratabilecek kadar olmamıştır.

Anahtar terimler: ısıl değişim; gönenç; ısıtma yükü; sınıflarda ısıtma; bedensel ısı salımı.

To My Parents

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

U-Value	: Co-efficient of thermal transmittance
MEB	: Milli Eğitim Bakanlığı (Ministry of Education)
TS	: Türk Standardı (Turkish Standard)
TSE	: Türk Standartları Enstitüsü (Turkish Standards Institute)
PEB	: Program on Educational Buildings
ISCED	: International Standard Classification of Education
TÜİK	: Türkiye İstatistik Kurumu (Statistics Office of Turkey)
OECD	: Organization for Economic Co-operation and Development
ASHRAE	: American Society of Heating, Refrigerating and Air Conditioning Engineers
SPSS	: Statistical Package for the Social Sciences

LIST OF NOMENCLATURE

A_{Du} : DuBois body surface area, m^2*

A : area of exposed building component, m^2

C : rate of convective heat loss from the skin, W/m^2 *

$c_{p,a}$: specific heat of air, kJ/(kg x ºC)

C_{res} : rate of convective heat loss from respiration, W/m^2 *

E_{res} : rate of evaporative heat loss from respiration, W/m^2 *

E_{sk} : rate of total evaporative heat loss from the skin, W/m^2 *

e : the partial pressure of water vapour in ambient air, kPa

e_{sw} : water vapour at saturation conditions, kPa

e_{sd} : saturation vapour pressure at dry-bulb temperature, kPa

f_{cl} : clothing area factor (A_{cl}/A_{Du})

g_i : solar transmission factor of glazing, unitless

$g_\perp$: solar transmission factor of glazing for the normal incidence, unitless

GLR : gain/loss rate, unitless

H : internal body heat, W/m^2 *

H_{con} : specific heat loss by transmission, W/K

H_s : total specific heat loss, $H_{s=} H_{con} + H_v$, W/K

H_v : specific heat loss by ventilation, W/K

h_{fg} : latent heat of vaporization of water, kJ/kg

h : coefficient of combined heat transfer, W/(m^2 * x ºC)

h_c : coefficient of convective heat transfer, W/(m^2 * x ºC)

h_r : coefficient of linear radiative heat transfer, W/(m^2 * x ºC)

h_e : convective evaporative heat transfer resistance at clothing surface (analogous to hc), W/(m^2 * x kPa)

hg : body height, m

I_{cl} : intrinsic insulation value of clothing, clo

I_i : solar radiation on vertical surfaces, W/m^2

i_{cl} : vapour permeation efficiency factor of clothing, unitless

k : unit conversion factor, (m^2 * x ºC)/(clo x W)

K_{res} : proportionality constant, (kg x m^2 *)/kJ

LR : Lewis relation, K/kPa

L : the latent heat of vaporization of water, kJ/kg

M : rate of metabolic energy production, W/m^2 *

$\dot{m}_{res}$: pulmonary ventilation rate, kg/s

n_v : air change rate, h^{-1}

P : barometric pressure at sea level, kPa

p_a : partial pressure of water vapour in ambient air, kPa

$p_{sk,s}$: water vapour pressure at skin surface (normally assumed to be that of saturated air at t_{sk}), kPa

Q : heating requirement, kWh

Q_{sk} : total rate of heat loss from the skin, W/m^2 *

Q_{res} : total rate of heat loss through respiration, W/m^2 *

Q_S : total sensible heat loss, W

Q_L : total latent heat loss, W

R : rate of radiative heat loss, W/m^2 *

R_{cl} : clothing insulation, m^{2*} *x* ºC/W

$R_{e,cl}$: evaporative heat transfer resistance of the clothing surface (analogous to R*cl*), m^2 * *x* kPa/W

rh : relative humidity, %

r_i : shading factor for transparent surfaces, unitless

RQ : respiratory quotient; the molar ratio of VCO_2 exhaled to VO_2 inhaled, unitless

t_a : ambient air temperature, ºC

t_d : dry-bulb temperature, ºC

t_{ex} : temperature of exhaled air, ºC

t_{ext} : temperature of exterior, ºC

t_{mrt} : the average of the mean radiant temperature, ºC

t_o : operative temperature, ºC

t_{sk} : skin temperature, ºC

t_w : wet-bulb temperature, ºC

V_{gross} : gross volume of the building, m^3

VO_2 : volumetric rate of oxygen consumption at conditions of 0^oC, 101 kPa L/min

V_v : ventilated volume, m^3

W : rate of mechanical work accomplished, W/m^2 *

wg : body weight, kg

$\boldsymbol{W_{ex}}$: specific humidity of exhaled air, unitless

$\boldsymbol{W_a}$: specific humidity of inhaled (ambient) air, unitless

$\boldsymbol{w}$: the fraction of wetted skin surface, unitless

$\boldsymbol{X}$: mass of water vapour (humidity ratio), kg/kg dry air

$\boldsymbol{\phi_s}$: mean solar gain, W

$\boldsymbol{\phi_i}$: mean internal gain, W

$\boldsymbol{\eta}$: utilization factor for gains, unitless

$_n$: net area, m^2

$_i$: orientation indicator

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* : these refer to body surface area

CHAPTER 1

INTRODUCTION

In this chapter are first presented, under respective sub-headings, the argument for and objectives of the study being reported on herein. Again under a dedicated sub-heading, it continues with a brief overview of the general procedure followed in its conduct and ends with a succinct description of what is covered in each of the remaining chapters, under the sub-heading titled "Disposition".

1.1. ARGUMENT

Whether from internal or external sources, we humans do not take well to bodily discomfort. Though we can endure it to a certain extent in terms of duration and intensity, we would rather not. Thus, once we perceive it through our senses, we seek to relieve it by some action. When experience tells us it is imminent, we either try avoiding the pending situation altogether or take precautions against it. For example: Moving to overcome muscular fatigue from staying in one position too long; or putting on special clothing to avoid getting cold and wet when going out into the snow.

Of all external sources, perhaps the one with a potential for creating the greatest long-term discomfort is our thermal environment. This is attributed to the nature of the mechanisms involved in overcoming its effects. The most significant of these are physiological and are first activated somatically, with only those of a mainly superficial nature left up to our voluntary action. The mechanisms themselves are well-described by GIVONI (1976) in regard to their architectural ramifications. To be noted here is that the two go hand in hand with respect to both range and extremes that can be tolerated, to thus define what we know as the zone of **bio-comfort**. A zone delineated by such factors as relative humidity, ambient temperature, rate of air movement and insolation.

The labeling as 'superficial' is, of course, merely in comparative terms. Indeed, the divers aspects of avoiding and/or overcoming thermal discomfort have constituted perhaps the most elemental and enduring endeavors of humanity throughout the ages. Among these, taking a predominant position have been the many manifestations of **shelter** it has evolved and has passed through. Manifestations which, according to DÜZGÜNEŞ (2005), represent the essence of its drive to first survive and then to sustain the mode and means of this survival–if not to seek its enhancement–regarding both physical and social aspects.

Certainly, neither the instinct to survive the vagaries of environment–and especially those of the thermal one–nor the seeking of shelter to ensure it are unique to humankind. As attested by ATTENBOROUGH (1989 & 1992), the many creatures roaming the divers domains of our planet for the most part do indeed display clearly recognizable if not highly remarkable behavior in this respect. Even more striking is that some of these creatures are seen to find the least likely places in which to carry on their survival–from the frozen wastes of the Arctic to the baking deserts of the Sahara. The fascination of humankind by the apparent success and efficiency of their designs has, from ages past, lead it to try not just uncovering the secrets underlying this, but with a rather simplistic and naive attitude, to also seek ways in which it could borrow from–even emulate outright–at least their most tangible features, ignoring that these were essentially phenotypical in nature. So much so that this was often at the expense of disregarding the innately superior faculties at its disposal for attaining even higher levels of success; one that could have readily been realized by taking a more holistic look at such creatures–not just as individual performers, but also as actors in their extended eco-systems.

Rather late in the day though it may be, such a point of view has eventually prevailed and become widespread enough to be called an actual turnaround. The tenets underlying the manifold current versions of this new outlook and its attendant nomenclature, including terms like 'bio-mimetics', 'bio-mimicry' and 'bio-inspiration', have been well-defined by BENYUS (1997c).

Be all this as it may, whatever the attributes by means of which such non-human creatures are presumed capable of displaying their so-called marvels of survival, these are merely those that are bestowed upon them, *gratis*; no more, no less. In other words, they are no reflection on any innate skill or capability to modify their being and/or existence as having come about through some voluntary action of their own. Surely some genetic mutations that allow them to continue their survival under changing conditions do occur; but when this lags too far behind, they simply become extinct, regardless of how successful they at one time were.

The concept here that does indeed distinguish human survival from that of other creatures is most aptly expressible by the term, 'enhancement'–as noted in passing, above. It is the many manifestations of this concept–based on our ability for abstraction and rationalization as they are, that holds the key to our success as a species, even though we seem to be otherwise poorly equipped. So it is that we set out to modify our mode of survival–if not in favor of comfort, at least for eliminating discomfort–instead of waiting for some act of Nature to do it for us: To create artifacts that take the toil out of everyday living; to build shelters for ourselves when and where none existed naturally; to alter the conditions of our environment to suit, if not to alter the very environment itself; and, in the words of MAJUMDER (1971), to transform ourselves from being mere food-gatherers–like the other creatures co-habiting our planet, to become food-producers; and, eventually, food processors.

Needless to say, especially early efforts were characterized by a great deal of ignorance. Thus, many were the mistakes made; and most with serious consequences. The greatest of these was the wanton exploitation of any and all things around us; things in seemingly endless supply and just there for the taking. On the other hand, increasing world population meant more and more of the same had to be taken. Also left out of the picture–unwittingly or not–for quite some time was the energy-equivalence of all these efforts. From the food-based metabolic energy of hand labor–considered 'benign' on the presumption it was renewable, to the non-renewable types consumed by industry-at-large, now condemned outright not just for being of fossil origin, but also for the by-products of their consumption, their emissions. Having, with such exploitation, come to the brink of global disaster and with a good part of our ignorance dispelled by way of our technology, a new approach for making the situation marginally more 'palatable' has recently emerged, so that now we have begun to exploit the very root of our own sustenance: Our food; ergo, 'bio-fuels'.

While increasing population played the most obvious part of all, the diversification of human activity that had to be 'sheltered' in one way or another, together with dropping thresholds of tolerable thermal discomfort, created such an enormous demand for more and ever more buildings of all descriptions and sizes that today, their production has come to consume the greatest part of total industrial energy. With all the elaborate machinery they now embody for doing this, perhaps even more goes into keeping the spaces they contain within the comfort zone. However, such extravagance cannot go on forever; nor can reliance be put on the currently-available forms of so-called renewable energy if accepted norms of comfort and convenience are still to be maintained. The devices employed for sapping such sources are in themselves consumers of even more polluting energy: The toxic by-products from the production of photovoltaics, the metallurgy involved in making windmills and the visual pollution created by both. Needed here are more subtle and thereby more effective approaches if long-term answers are to be found. One such approach is certainly energy-efficient design.

Among all the types of building evolving from the activities of humankind as these diversified in response to its drive for enhancing its mode of survival–and especially its social one, perhaps the most noble and notable has been that for sheltering the education of its very young; namely, primary schools. These are also facilities that therefore demand the utmost care in how they resolve the matter of providing thermal comfort for their occupants: Children. Not just because children happen to be more vulnerable than adults in terms of bodily stature, but also because their capabilities for coping with thermal discomfort, both somatic and superficial, have not yet become developed enough to be accounted for on the same basis and according to norms in place for such, as has mostly been the case so far.

Questions that came to mind in this respect were many. To cite a few: How much metabolic heat do children radiate when at rest compared to when they have just come in from outdoor or indoor play? Can this be taken into account when determining the heat load of class-rooms? Do differences exist for different age groups? For gender? Does classroom size and/or occupant density have any bearing on their thermal environment? Should classrooms therefore be equipped to provide instant thermal responses to such variables? How significant is classroom orientation? Classroom aspect ratio?

While it was to resolve–if not to answer outright–these and several other impingent questions that the study was initially undertaken, realization of the complexity that would thus be involved made it necessary to narrow its scope and to delimit its sample space. Hence, confinement of its subject domain to publicly-run primary schools within the city limits of Ankara; and then, to those built after 1998 in just one of its districts: the District of Çankaya.

1.2. OBJECTIVES

The conceptual framework of the study broadly rested on the recently-revived body-centred outlook described by BENYUS (1997c). In this context, its primary focus was on bio-comfort rather than on any of the other bio-oriented domains cited therein. Following from the argument, objectives were therefore confined to those involving the attainment of bio-comfort for children in the classroom environment. While in some aspects these overlapped with those postulated much earlier by FANGER (1970), they were defined with both implicit and explicit emphasis on the stature of the occupants in question. Four fundamental objectives were thus established; namely:

a) to understand the thermal environment of primary schools and the effect of this environment on their occupants, the students;
b) to understand the thermal response of students to their thermal environment and their interactive relationship with it;
c) to formulate a mathematical model that would express the mechanisms involved in establishing the requisite heat balance for schoolroom occupants; and
d) to calculate the thermal effect of students on the heating load of classrooms in terms of their body size.

1.3. PROCEDURE

A general survey was first conducted to establish familiarity with the subject domain, which included thermal properties of the school environment in regard to its potential effect on the thermal response shown by students. Next was defined the sample space of the study as per the delimitations stated in Section 1.1, above, from which a random sample of relevant size could be drawn. After these were identified with all their pertinent physical attributes came an interim phase where an extensive search was made in the literature to obtain specific information not only on the physiological and physionomical characteristics of the student body in question, but also on gernane operational procedures and formulations by means of which these could be utilized.

Thus were first investigated whether or not there were any disparities in the amount of heat generated by students that could be ascribed to differences among the age groups presumed for the 8 grades of primary education. This was followed by calculation of sensible heat gains within and among age groups in terms of ambient environmental conditions by using the heat balance equation given in the literature by ASHRAE (1989) as based the model proposed earlier by Fanger (1970, 1978). In the fourth phase were then defined sensible heat values as internal heat gains during the routine heating period in order to calculate heating load levels for each grade. In the last phase, statistical tests were performed on measured and calculated data to determine whether or not the broad range of body sizes and class-room occupancy densities caused any significant differences that could influence the heating requirements of school buildings insofar as energy savings were concerned.

1.4. DISPOSITION

There are five chapters to this report. This first, containing the argument, the objectives and the procedure of the investigation, along with this disposition which summarizes what follows in the remaining chapters, gives a broad view of its most salient aspects.

The second consists of a literature review on various aspects of primary school facilities, including certain relevant thermo-physical attributes of both students and classrooms that focus on their interaction in attaining thermal comfort by considering heat loss from students as an active factor. The third chapter provides a thorough description of study material, as both the physical setting and the potential occupants of this setting, together with the method used to first identify the study domain (sampling) and then in arriving at the results expected from the investigation proper. The fourth then sets out the specific results obtained from the analyses described in the preceding chapter and discusses these in light of its objectives and the reports of the literature. The fifth concludes the study by summarizing its findings and offering pertinent recommendations.

CHAPTER 2

LITERATURE SURVEY

A total of 61 sources were covered in this survey. Owing to the nature of the subject matter and of the investigation itself, these necessarily encompassed marked diversity, ranging from reports dealing directly with the issue at hand to those on background and methodology. Certain others, on the other hand, were used merely as sources of quantiative or descriptive inputs, such as meteorological data and normative values for the performance and physical properties of subject matter. To maintain clarity of relevance in the face of such diversity, they have thus been ordered under six sections–each embodying a number of pertinent sub-sections–in the following summary as: 1) reports on background, past and present; 2) reports on attributes of the classroom environment (including its occupants; 3) reports on the interaction of occupant and environment; 4) reports on factors, indices and formulations; 5) reports on methodology; and 6) sources for operational data. Since many of these sources were involved in more than one domain, individually quoting how many were cited under each did not seem to be meaningful here.

2.1. REPORTS ON BACKGROUND, PAST AND PRESENT

What follows is a selective iteration from the relatively large number of sources on this particular aspect, as it was considered to have only a marginal bearing on the study proper. These are cited under the three discrete sub-headings below, as: reports on the rôle of primary education, in general; reports on past and present aspects of primary education in Türkiye; and reports describing the physical setting of early primary education in Türkiye.

2.1.1. Reports on the rôle of primary education, in general

Arguing that the principal determinants of how the primary education system of any given country is structured are the very social, cultural, economic and other macro features that also characterize it, both KOL (2003) and GELİŞLİ (2005) cite in evidence the controversial transition from the strictly ecclesiastical *Sübyan Mektepleri* (Juvenile Schools) of the Ottoman era to the distinctly secular ones established once this era had ended.

To quote from another source, the Program on Educational Building (PEBc, 2006: 4), "Education plays a pivotal rôle in the growth and personal development of individuals as well as in the prosperity of countries." Based on the International Standard Classification of Education established in 1997 (ISCED-97), the same source distinguishes five levels of education to be: a) pre-primary; b) primary; c) lower secondary; d) upper secondary; and e) tertiary. In this vein, primary education is defined to be where children acquire not only the basics of "read'n, writ'n 'n 'rithmetic", to use a well-worn Americanism, but also that of personal skill development and conduct. While on these grounds alone it is generally conceded to be a compulsory phase, MEDD (1976) does point out that it may not be universally so, local authorities having the final say in this respect.

2.1.2. Reports on past and present aspects of primary education in Türkiye

When tracing the transition noted earlier in more detail, GELİŞLİ (2005) points out that as is the case with such historical events, it was never one that occurred overnight, since the social and cultural forces in question had begun their push for change as early as the mid-19th Century; specifically, with the *Tanzimat* (reformation) Movement of 1847. The author continues with mention of some secular primary schools that had already been established by that time while noting that, in deference to the canonic custom of the era, none were co-educational.

According to KOL (2003), it was the advent of planned development in 1963 that spawned another turning point where educational policies and structuring, especially that of primary schools, were concerned. A turning point that stirred up considerable controversy and debate at the time, not only with regard to matters of content and method, but also to the proposed transition from gender-based segregation to co-educational integration; and, as the author notes, this was despite the argument for such integration being basically economical: More efficient and effective use of available classroom space.

As again reported by both KOL (2003) and GELİŞLİ (2005), the most recent upheaval came about in 1997 when compulsory primary schooling was by law extended from 5 to 8 years with the integration of lower secondary schooling into the program–which, until then, was a non-compulsory 3-year one, such to be effective as of the 1998-1999 Academic Year.

2.1.3. Reports on the physical setting of early primary education in Türkiye

The most comprehensive account in this regard is given by ELGİZ (1978). Remarking on the time sharing, or 'binary', scheme still in practice today, the author argues that, while resort to this was initially inevitable due to the backlog of school-age children and the shortage of both classroom facilities and teachers accruing from earlier times that were needed to implement the mandate of compulsory primary education, the false convenience of maintaining the *status quo* and the subsequent economies realized by thus not having to allocate additional funding for new facilities readily became the default condition. The same author goes on to note that as the basic concern of policy-makers was quantity rather than quality even when taking remedial steps became inescapable in the 1970s, the result was mass replication of some low-standard design that could be built as cheaply and as quickly as possible with practically no regard for comfort parameters. Confirming that this practice continued well into the 1980s, KALTAKÇI, ARSLAN, YILMAZ & ARSLAN (2008) go further to state that this approach still remained in practice even after the Integration Act of 1997.

Citing from an in-house circular of the Ministry of Public works under whose jurisdiction the designs noted above were undertaken at the time by its Directorate-General of Construction, ÖZYABA & ÖZYABA (http://www.kentli.org/makale/ilkokul.htm; accessed: 2008.) summarize the key features prescribed for them therein, where the main distinction was only with respect to climate and orientation; thus:-

– for hot and humid climates, prescribed was a north orientation to maximize wind exposure and shading and to minimize humidity levels by location on high ground;
– for hot and arid climates, prescribed was an east-west orientation with location on level ground;
– for temperate climates, prescribed was a location on the skirts of sloping ground with no restriction on orientation; and
– for cold climates, prescribed was an orientation to maximize solar heat gain and minimize wind exposure.

The same authors do note, however, that it was often impossible to meet even these minimal conditions due to constraints imposed by topography, by access and by the availability, configuration and cost of property.

Then again, in their study on the conformity of existing classrooms to the Ministry of Education Specifications for Building and Construction, ÜNAL, ÖZTÜRK & GÜRDAL (http://egitimdergi.pamukkale.edu.tr; accessed: 2008) report that while this was within acceptable limits in regard to size, they did not meet prescribed standards of comfort–a situation which they ascribed to overcrowding. The authors–together with KOL (2003)–do note, however, that much work, encompassing both renovation of existing facilities and new construction, has nevertheless been done to not only accommodate the 8-year curriculum mandated by the 1997 act, but also to phase out binary scheduling.

Broad quantitative aspects are reported by two government agencies as official statistics, one being the Statistics Office of Türkiye (Türkiye İstatistik Kurumu: TÜİK) and the other, the Ministry of Education (T. C. Millî Eğitim Bakanlığı: MEB). Of such, only those pertinent to the study–itself delimited to primary schools within the Çankaya District of Ankara–were considered here in the interest of brevity. Thus, according to the former (TÜİK), mean values of primary school enrolment in Ankara as a whole for the 2007-2008 Academic Year were 615 per school, with 38 per available classroom (www.tuik.gov.tr., accessed on: December 21st, 2008). Being more detailed, that from the latter is summarized below in Table 1.1.

Table 1.1. Summary of primary school enrolment statistics for the Çankaya District of Ankara, by type of schedule and by grade for the 2007-2008 Academic Year.

Number of schools	Number of classrooms	Type of schedule single	binary	Grade 1	2	3	4	5	6	7	8
103	1935	67	36	8546	9113	9009	9628	9294	9973	9642	9677

Source: MEB Çankaya District Office.

2.2. REPORTS ON ATTRIBUTES OF THE CLASSROOM ENVIRONMENT

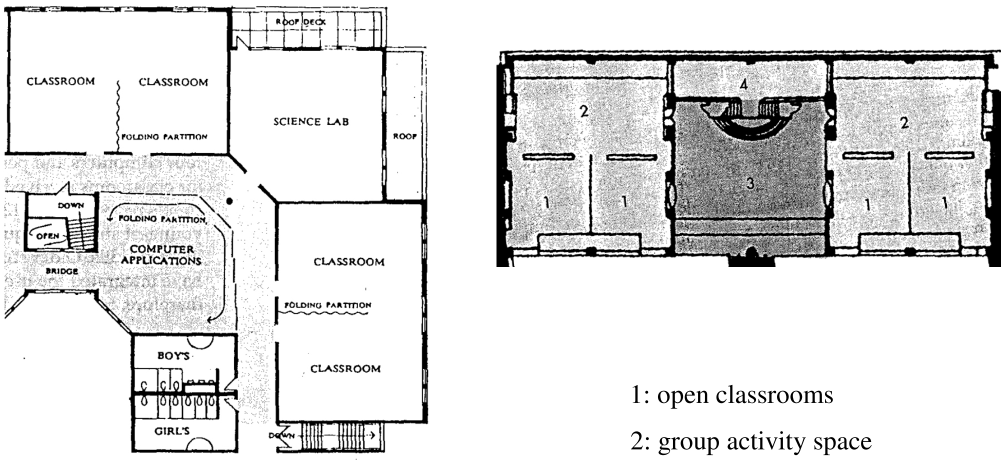
The greatest number of sources belonged to this domain. The most salient of these have been cited below under three discrete sub-headings, as: reports on the physical attributes of classrooms, reports on the ambient attributes of classrooms and reports on attributes of classroom occupants.

2.2.1 Reports on the physical attributes of classrooms

It was the middle of the last century when CAUDILL (1954) voiced the idea that the approach to school design should start from due consideration of its educational precepts. Thus, it would be not just the number of students to be accommodated, but also the intended type of activity that would be primary determinants of both the size and the shape of its work spaces.

The same author further stipulated that schools should be thought of as interactive environments where the health and bodily comfort of their occupants, the students, are given even more consideration than their mere regimental accommodation.

Noting changes in such design precepts resulting from developments in information technology as well as in teaching methods, modes, media and venues, the Organization for Economic Co-operation and Development (OECD, 1995) redefines the classroom as just one of the 'places for learning' and thus questions the formal concepts of classroom occupancy, function and configuration. On a more tangible stand in this vein are the several examples of such 'places' given by OECD (1995), two of which are reproduced in Figure 2.1, below. In the River Oaks school, designated as example (a) here, two large classroom spaces–which themselves can be sub-divided into two discrete work areas–surround a 'resource centre' consisting of a science laboratory and a space for computer applications, while in the Ueno School, designated as example (b), are two pairs of open classrooms, marked ‘1’, joining onto their respective group activity spaces, marked ‘2’.

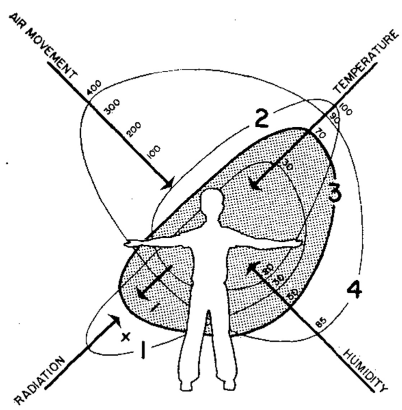


(a) (b)

Figure 2.1. Typical examples of 'places for learning':
(a) River Oaks Elementary Public School, Canada;
(b) Ueno Elementary Public School, Japan
(Source: OECD, 1995)

2.2.2. Reports on the ambient attributes of classrooms

It was again CAUDILL (1954) who very early on pointed out the significance of ambient attributes–as light, acoustic and air properties–for classroom environments in maintaining the learning attention of their occupants. While noting the rôle of window placement, size, shape and orientation, together with the negative effect of uncontrolled noise in this regard, the author argues that it is the last, air–with its temperature, moisture content and movement–which plays the most effective part in securing the prerequisite conditions. The author goes further in this vein to the extent of composing–with the addition of a thermal radiation factor–a polar chart that outlines threshold zones of thermal comfort for students under different sets of conditions. In this chart, reproduced below as Figure 2.2, the first polar curve defines a zone where low air temperature demands only additional input of radiant heat as both humidity and air movement would be self-defeating, while the second defines one where the combination of high ambient temperature and low humidity calls for lowered air speed to prevent skin dryness and irritation. Here, it is the third polar curve that defines an optimal zone such that, with an air temperature of 21°C and a relative humidity of 50%, no inputs on the other two counts are called for. The fourth then defines the case for high temperature and humidity, where both radiative and evaporative heat loss must be maintained for similar conditions of comfort.



(temperature is in degrees Fahrenheit)

Figure 2.2. Polar chart by CAUDILL (1954), showing relationships between radiant heat and attributes of ambient air for providing comfort.

Commenting on the scientific merit of such early studies, CORGNATI (2007) emphasizes that, whatever their shortcomings may have been, they do indeed deserve all due recognition for the ground-breaking contribution they made to the advent of approaches in school design where the health and well-being of students became of primary concern.

Following in these footsteps was the now-well-known **comfort theory** as advanced by FANGER (1970) which, based on the concept of **thermal neutrality**, held that the thermal environment of schoolrooms could at best be optimized for about 80% of its occupants, the stipulation being due to potential fluctuations in the radiant field. This aspect is to a certain extent confirmed by the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE: 1991) when noting that indoor climatic conditions of schools are bound to show considerable variation owing to the diversity of activities and spaces that they are obliged to encompass.

Defining thermal comfort as a function of thermal sensation, McPHERSON (1993) goes on to state that, further to the ambient attributes of air–as temperature, humidity and velocity used by most other investigators, additional factors to be considered in attaining this are the metabolic rate, hence, the age, and the clothing conditions of occupants as well as mean radiant temperature. With reference to the potentially negative effect of this last factor on student comfort by way of heat loss to colder–or gain from warmer–room surfaces by radiation when their temperature has not equalized with ambient air temperature, such as at the start-up of the daily heating cycle during winter, TERRY (1960) very early on emphasized the necessity for keeping this temperature steady by provision of both thermostatic control and appropriate insulation for classrooms. Along the same lines, HUMPHREYS (1977) argues that erratic temperature variations during the course of a day are likely to cause greater discomfort for occupants than any given level of it, especially when these are young children, as such cannot be expected to keep changing their outer garments accordingly.

On the other hand, the findings of an early experiment in this domain, as summarized by McLURE (1972), showed that–contrary to what was commonly presumed at the time–air temperature had the strongest effect on both bodily comfort and mental well-being compared to humidity and air movement. It was nevertheless reported that the increased pulse and respiration rates caused by lowered heat dissipation from the body via evaporation under conditions of high humidity did notably decrease student performance.

While in an earlier study based on teacher reports, HUMPHREYS (1974) concludes that an ambient temperature of 19 to 21^{o}C is an acceptable level for general classroom activities, the recommendations of ASHRAE (1991) are not only numerically higher, but also distinguish between winter and summer conditions, with 22^{o}C being stipulated for the former and 26^{o}C for the latter, at a maximum sensible heat factor of 0.75. These and ambient air temperatures for other activity areas in schools given by this source are summarized in Table 2.2, below. ÇAKIROĞLU (1962) makes a similar distinction, but according to class time, stating that it should be 16 to 17^{o}C at the beginning of sessions and not exceed 20 to 21^{o}C at their end. Turkish Standard TS 2164 (1983) stipulates a temperature of 20 ^{o}C as the optimum value for school buildings in Türkiye.

Table 2.2. Winter and summer ambient air temperatures recommended by ASHRAE (1991) for various activity areas of schools, in degrees Celsius.

Type of space	Winter	Summer
classrooms, laboratories, auditoria, libraries, administration areas, *etc.*	22	26
locker and shower rooms	24	-
toilets	22	-
storage areas	18	-
mechanical rooms	16	-
corridors	20	27

Developments in the mechanical plant to provide supplementary input for maintenance of the thermal comfort conditions being thus stipulated are traced by McLURE (1972) while those that had evolved for heating purposes alone were earlier classified by TERRY (1960), who identified them as systems using steam, systems using hot water, systems using warmed air and systems using electrical resistance. The specifications published by MEB (2001) stipulate the use of hot water systems for all new integrated primary schools and suggest zoning of administrative areas from other in-house facilities due to the inherently different occupancy densities involved.

Becoming a mandatory standard as of 1998 for all new construction, the thermal properties of school buildings are also estimated according to Turkish Standard TS 825 (1998), which asks for resolution of such according to an overall co-efficient of thermal transmission, "U", together with checks for potential condensation on inner surfaces of exterior envelope elements. It is a matter of common mechanical engineering tenets that, apart from its function as a delaying barrier against direct penetration in maintaining expected temperature differentials, this latter aspect constitutes the principal consideration in determining insulation requirements for such elements.

2.2.3. Reports on attributes of classroom occupants

No reports were found that specifically dealt with attributes relevant to the study. What did exist was confined to those of the adult human body as were considered crucial for its thermal comfort in the environment-at-large. Be this as it may, it is these that have nevertheless been cited here, under the *a priori* presumption that they would, at least in a general way, hold for the subject age group as a sub-set of the human population. Thus are taken up:

Physiological attributes:

Considering the issue a subjective one, HENSEL (1979), for example, distinguished between temperature sensation and thermal comfort, stating that the latter was more readily expressed by subjects as being 'pleasant' or 'unpleasant'. Admitting, however, that such evaluations necessarily involve perceptive integration by respondees of thermal afferents from internal as well as cutaneous thermo-sensors, the author did later come around to say that these studies are better-served by empirical models which take into account the overall heat balance of the body as regulated by both autonomic and behavioral action. Ergo, the schematic outline, shown in Figure 2.3, below, devised by this author to depict the interaction of these two factors.

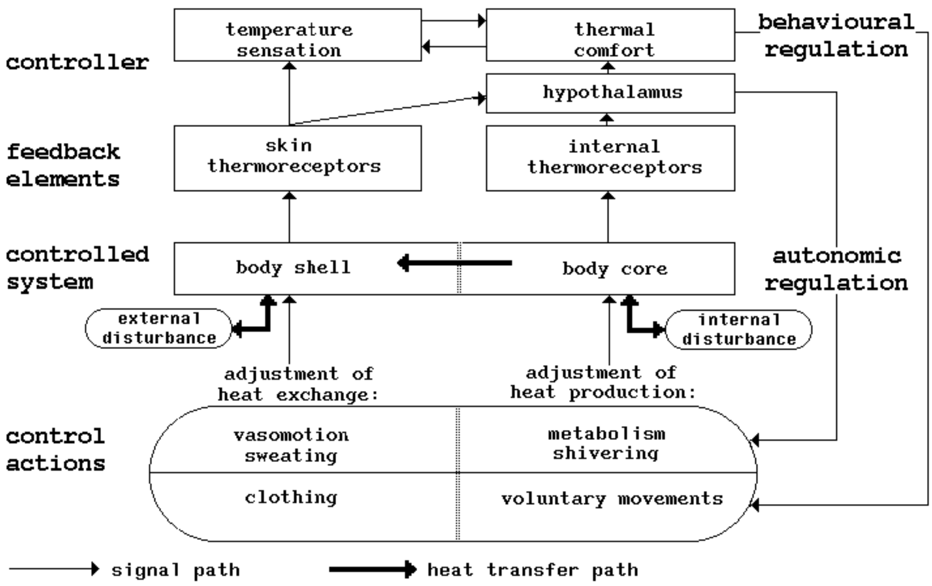


Figure 2.3. Schematic outline of autonomic and behavioral temperature regulation in the human body, according to HENSEN (1990).

The autonomic aspect was also noted earlier by BEDFORD (1974) who, in perhaps more colourful terms, had called it 'thermostatic control' and had described it as a built-in system for keeping body core temperature–the temperature of vital internal organs–within a steady but narrow range. While GIVONI (1976) gives the average value of this temperature as 36.5°C, ASHRAE (1989) puts it slightly higher, at 36.8°C.

Both GIVONI (1976) and HENSEN (1990) define the physiological mechanisms of the body controlling its autonomic responses to be:-

a) vasomotor regulation: the dilation/constriction of blood vessels in the peripheral, or subcutaneous, layers of the body to reduce/increase the rate of blood flow;

b) water discharge from the body: passive water loss from the lungs and skin, as insensible and active water loss from sweat glands, as sensible perspiration;

c) pulse, or heart, rate: the regulation of oxygen supply, hence, metabolic rate.

What they then cite as behavioral ones are bodily activity and the addition or removal of clothing.

Of further note is the study by BENZINGER (1979) which showed that the rate of sweating was a near-linear function of core temperature, as depicted by the scatter plot of Figure 2.4 below. ZHANG, ARENS, HUIZENGA & YU (2001) later point out that among factors to be considered in defining comfort levels for occupied spaces should also be included individual characteristics of physionomy, such as body density and body surface area.

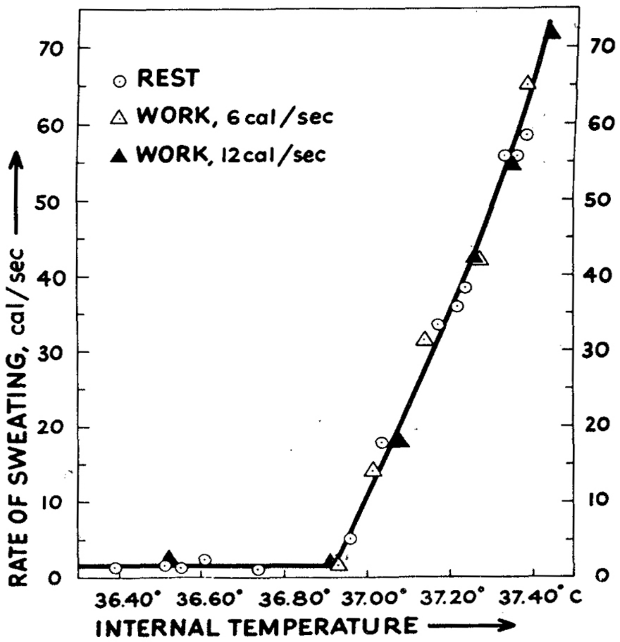


Figure 2.4. Scatter plot for rate of sweating versus core temperature, as determined by BENZINGER (1979).

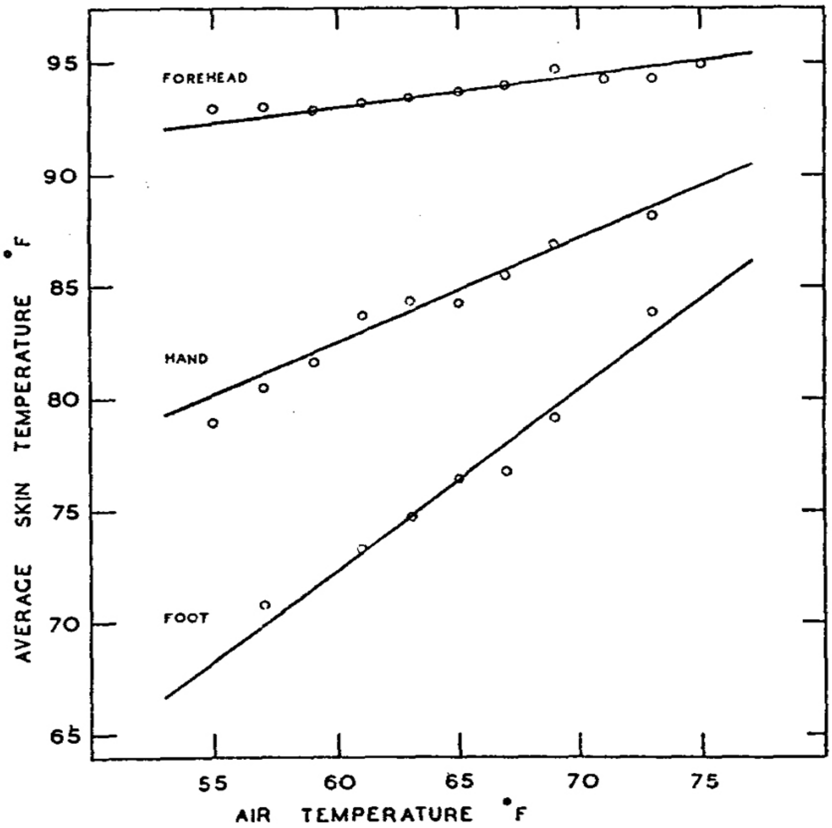
Noting that vasomotor regulation is the first physiological mechanism to be activated in response to variations in the thermal environment, GIVONI (1976) explains that the mechanism itself hinges on the thermal capacity and conductivity of blood which, being made up mainly of water, is able to carry and transfer large quantities of heat with even small changes in its temperature. The author continues to say that as the tissue of peripheral body layers is rich in fat–which has poor thermal conductance–it is the blood content of this layer that determines its performance in heat dissipation: raised when increased by vaso-dilation while lowered when decreased by vaso-constriction; and further points out that under hot conditions, the overall volume of blood in the body also increases; albeit, along with an elevated pulse rate.

In dwelling on the second mechanism, GIVONI (1976) notes that as passive water loss from both skin and lungs is almost unaffected by ambient temperature but depends primarily on a difference of vapour pressure between the body and ambient air–a difference which decreases with a rise in the latter, it cannot be considered an effective mechanism under external heat stress. What is so in this regard, the author continues, is the eccrine secretion of sweat glands distributed all over the body–controlled either by cutaneous heat receptors or by the thermo-regulation centre in the hypothalamus of the brain–and from where this secretion evaporates to produce cooling, the highest being when it takes place at the mouth of sweat pores so that all the latent heat of vaporization comes direct from the body; lower when it forms drops on the skin, in which case most of this heat is absorbed from the surrounding air; and lowest when it takes place from clothing that has absorbed these drops.

As an aside, GIVONI (1976) points out that, in addition to activating the thermo-regulatory mechanisms of the body, drops in ambient temperature below the comfort zone also lead to a rise in what is known as muscle tone which, while elevating metabolic rate, concurrently reduces the working efficiency of muscles so that tasks requiring their use take more effort than under comfortable conditions. Continuing, the author comments that in extreme cold, this increase may reach a level high enough to cause involuntary shivering, which also increases metabolic rate 2 to 3 times above that in the comfort zone, even though the body may be at complete rest.

Citing pulse, or heart, rate as one of the most important physiological mechanisms of the body, GIVONI (1976) points out that by so regulating oxygen supply, it also controls its rate of heat exchange in different and varying conditions of work, environment and clothing. The author further notes that it thereby acts as the main indicator of thermal or metabolic stress.

What was considered particularly noteworthy, however, were the reports on the rôle played by skin temperature in regard to these mechanisms. Defined by BEDFORD (1974) as a critical factor in the estimation of heat exchange between the body and its surroundings, it is shown by the author to vary not only with ambient air temperature but also with location under the same temperature conditions in the scatter plot of Figure 2.5 given below where it is seen to be highest on the forehead and lowest in the feet.



(temperatures are in degrees Fahrenheit)

Figure 2.5. Scatter plot of average skin temperature over the body with respect to ambient air temperature, according to BEDFORD (1974).

On this point, both GIVONI (1976) and McPHERSON (1993) call attention to the fact that as skin temperature is not uniform over the body surface but may vary from 15 to 42°C, temperature gradients between the body core and the skin are quite different from one point to another–which in themselves show variations of up to 10°C under the same conditions of the thermal environment. Noting that while such differences tend to even out at higher ambient temperatures, the authors point out that they should nevertheless be taken into account for heat balance studies by measurements taken at representative locations (usually 16) to give a **weighted mean skin temperature**, where weights are according to the relative sizes of the skin areas in question and cite this to be about 34°C under comfortable conditions.

While FANGER (1970) contends that skin temperature can be considered as an indicator of metabolic heat production per unit of body surface area, McPHERSON (1993) puts forth the idea that mean skin temperature is a function of ambient air temperature, as shown in Figure 2.6, below.

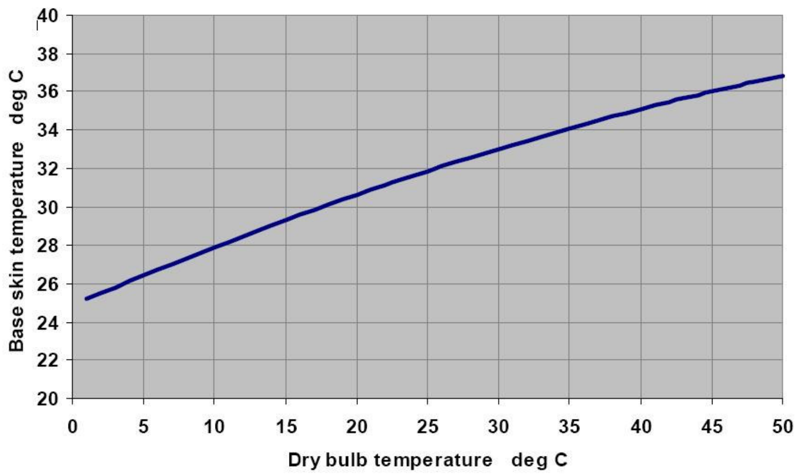


Figure 2.6. Mean skin temperature as a function of ambient air at low velocity and 40% relative humidity according to McPHERSON (1993).

Superficial attributes:

Two determinants are seen to be of concern here: a) body surface area; and b) nature of attire (clothing). Regarding the former–already cited from ZHANG, *et al.* (2001) in a general context above, BEDFORD (1974) refers to the work by DuBOIS & DuBOIS (1916) as putting forth the most accurate method of measurement; a method based on the weight-to-height relationship of the nude body that estimates this according to the equation:

$$A_{Du} = (wg^{0.42} \times hg^{0.725}) \times 71.84, \quad (2.1)$$

where the first term in brackets is weight and the second, height, while the 71.84 is a constant derived by DuBOIS & DuBOIS (1916) . BRUEN (1930), in reference to the same study, considers this formula as a comparison standard for determining the age gradient of basal metabolic rate, as cal/m^2/hr (calories per unit area per hour). On the tenet that metabolic heat pro-duction is a function of heat transfer to or from the body per unit surface area, as clarified by BEDFORD (1974), ASHRAE (1989) gives this to be 1.8m^2 for an adult male with a body mass of 70kg and a body height of 1.73m. DURNIN (1981) holds, however, that this tenet does not sufficiently explain the phenomenon in question due to fact that meta-bolic rate is also a function of such physionomical parameters of human beings as age and gender. In this vein, ZHANG, *et al.* (2001) argue that since basal metabolism is recognized as a function of gender as well as of body weight, height and surface area, all such attributes should be included in heat gain/loss calculations for determining the ther-mal response of occupants.

BEDFORD (1979) later notes that, with due recognition of the difference in exposure involved for heat gain/loss calculations, this formulation was subsequently revised to account for occupant position, as sitting and standing; a revision that gave what was called the **effective radiation area factor**. Studies by FANGER (1970) had yielded this as 0.696 for a seated person and 0.725 for a standing one; values that were independent of gender and body size.

About the second, nature of attire: While CAUDILL (1954) states this to be a matter of school regulations, where the attire specified more often than not takes student comfort as the very last consideration, the study by HUMPHREYS (1977) shows this to be a significant factor in controlling the indoor climate of classrooms. So much so, the author notes, that students in light clothing were able to comfortably tolerate an ambient air temperature higher by 4^{o}C compared to those in regulation attire under the very same activity conditions. The experiment by BERGLUND (1979), where subjects wearing different levels of clothing were exposed to varying levels of ambient air temperature, also confirmed that the nature of attire was an effective factor in assessing the thermal performance of a space. Even earlier pointing out the need to consider the physical and mechanical properties of attire such as permeability, material and weave in taking sensible heat measurements, FANGER (1970) proposes compilation of a **clothing factor**, the tabulated values of which could then be directly entered into the necessary calculations.

Only much later does work in this direction appear, as the compilation by ASHRAE (1989) for the insulation values of various indoor clothing ensembles, with the assumption that they are uniform over the entire body. A sample of these is given in Table 2.3, below, where the insulation values are designated by the symbol, I_{cl}, and their surface area factors, by the symbol, f_{cl}. Since the unit for the former, the ***clo***, cannot be entered directly into heat calculations, a conversion factor, k, is used to obtain compatible values, R_{cl}, where $R_{cl} = k \times I_{cl}$ and $k = 0.155$. Another factor affecting the level of evaporative cooling is cited as the moisture resistance of clothing, $R_{e,cl}$, which is calculated from the equation:

$$R_{e,cl} = R_{cl} / i_{cl} \times LR, \qquad (2.2)$$

where i_{cl} is the vapor permeation efficiency factor which, for normal indoor clothing, is taken as 0.45; and LR is a constant, taken as 16.5 for indoor conditions between 25 to 40°C at atmospheric pressure, called the Lewis Relation.

2.3. REPORTS ON THE INTERACTION OF OCCUPANT AND ENVIRONMENT

Also quite extensive in number, the iteration of studies falling in this domain have again been confined to those considered most salient and germane. Though closely related, they have nonetheless been compiled under three discrete sub-headings for clarity, as: reports on the rôle of metabolic rate, reports on the rôle of activity level and reports on thermal interchange models.

2.3.1. Reports on the rôle of metabolic rate

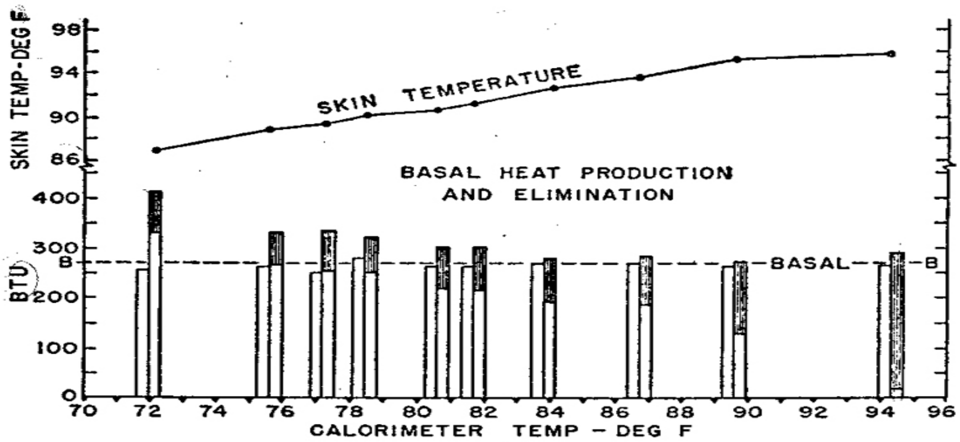
As an output of food ingestion, GIVONI (1976) explains, while the rate of metabolic heat generation by the body is generally considered proportional to body weight, its level at complete rest in a lying position is referred to as **basal metabolism**–noting that this is different from its lowest level, which occurs during sleep. Calling attention to the fact that the rate at which this metabolic heat generation then increases to provide the additional energy needed when the body becomes engaged in some activity is always disproportionately higher than what the mechanical equivalent of this activity actually requires, the author points out that what makes discharging the 'unused' part of this heat from the body a crucial issue in maintaining a stable core temperature simply stems from the inherent inefficiency of the body itself as a 'heat engine'.

Table 2.3. Insulation values for typical clothing ensembles according to ASHRAE (1989).

Ensemble description[a]	I_{cl}, clo	I_r, clo[b]	f_{cl}
Walking shorts, short-sleeve shirt	0.41	1.05	1.11
Fitted trousers, short-sleeve shirt	0.50	1.12	1.14
Fitted trousers, long-sleeve shirt	0.62	1.22	1.19
Same as above, plus suit jacket	0.96	1.54	1.23
T-shirt, loose trousers, long-sleeve shirt, long-sleeve sweater	1.01	1.56	1.28
T-shirt, long underwear bottoms, loose trousers, long-sleeve shirt, long-sleeve sweater, suit jacket	1.30	1.83	1.33
Sweatpants, sweatshirt	0.77	1.37	1.19
Knee-length skirt, short-sleeve shirt, panty hose (no socks), sandals	0.54	1.10	1.26
Knee-length skirt, long-sleeve shirt, full slip, panty hose (no socks)	0.67	1.22	1.29
Knee-length skirt, long-sleeve shirt, half-slip, long-sleeve sweater, panty hose (no socks)	1.10	1.59	1.46
Ankle-length skirt, long-sleeve shirt, suit jacket, panty hose (no socks)	1.10	1.59	1.46
Long-sleeve coveralls, T-shirt	0.72	1.30	1.23

a: Unless otherwise noted, all ensembles include briefs or panties, shoes and socks
b: For mean radiant temperature equal to air temperature and air velocity less than 0.20 m/s.

Unless there is a state of absolute thermal equilibrium–according to McPHERSON (1993) a rarity–the body attains the heat balance necessary for a stable core temperature as well as for maintaining a sense of comfort by an ongoing process of thermal exchange with its surroundings; more specifically, by loss or gain at the body surface–the skin–through the physics of radiation, convection and evaporation. Based on the results of an experiment reported by ASHRAE (1967), Figure 2.7, below, shows the relation between weighted mean skin temperature and heat loss by these mechanisms at different ambient conditions.



Normal control, naked, in calorimeter at temperatures from 72.8 to 94.1 F. First column in each experiment represents heat production as determined by indirect calorimetry, the second column, heat elimination. The portion marked with vertical lines represents vaporization; the unmarked area, radiation, and convection. The skin temperature represents the average reading of 18 spots on the surface.

(temperatures are in degrees Fahrenheit and heat values, in British Thermal Units, BTU)

Figure 2.7. Relationship of heat loss from an adult body by evaporation, radiation and convection with skin temperature, according to ASHRAE (1967).

2.3.2. Reports on the rôle of activity level

In this context, FANGER (1970) notes that the magnitude of metabolic heat released by the body can be considered as a function of the particular activity in which it becomes engaged, including its intensity and duration. NISHI (1981), in ASHRAE (1989), sets out the metabolic heat equivalent of selected activities according to the empirical equation:

$$M = 352 \times (0.23 \times RQ + 7.77) \times Vo_2/A_{Du}, \quad \text{............................(2.3)}$$

where M is the value of metabolic heat rate, RQ is the respiratory quotient, Vo_2 is the volumetric rate of oxygen consumptions and A_{Du} is body surface area calculated from equation 2.1. A sample of these is provided in Table 2.4, following, while the full listing is given in Appendix A.

Table 2.4. Metabolic heat equivalents for some typical activities, according to NISHI (1981).

Activity	W/m^2	met[a]
Resting:-		
Sleeping	40	0.7
Reclining	45	0.8
Sitting	60	1.0
Standing	70	1.2
Walking:-		
0.89 m/s	115	2.0
1.34 m/s	150	2.6
1.79 m/s	220	3.8
Office work:-		
Reading, seated	55	1.0
Writing, seated	60	1.0
Typing, seated	65	1.1
Filing, seated	70	1.2
Filing, standing	80	1.4
Walking about	100	1.7
Lifting/packing	120	2.1

a: 1 met = 58.2 $W7m^2$

2.3.3. Reports on models of thermal interchange

Based on the assumption that thermoregulation is primarily a function of the autonomic control system as they were, early models focused on the implicit mechanisms of this system essentially in terms of mathematical formulations. In this vein, while that by GAGGE (1973) proposed one consisting of two concentric shells, an outer skin layer and an inner core, that by STOLWIYK (1970) considered a 'standard' body weighing 74.1kg and having 1.89m^2 skin area in terms of six cylindrical components with each comprising four layers–as core, muscle, fat and skin–over a central one of blood vessels; and that by WISSLER (1970) had 15 cylindrical body components, each with three sub-systems as arteries, veins and capillaries.

As SMITH (1991) notes, though it was developing technology–especially in the area of virtual simulation–that enabled construction of models incorporating ever more complex aspects, both physiological environmental, most of these, such as that by HUIZENGA, HUI & ARENS (2001), were not always universally applicable as they were often intended for specific purposes. MURAKAMI, KATO & ZENG (2001), pointing to the huge amounts of data needed to model not only the thermo-physiology of the human body but also its shape in due detail, note that it is therefore almost impossible to obtain the level of accuracy that such simulations seem to promise. Improvements in both soft- and hardware nonetheless allowed FIALA, LOMAS & STOHRER (1999) to later develop a computer model that simulated at least the passive thermo-regulation system acting within a non-uniform variable environment for a clothed body made up of 15 components where 1 was spherical and the remainder, cylindrical, with 4 to 5 tissue layers per component. The integration of this with the active system had to wait for the work by LICHTENBELT, FRIJNS, FIALA, JANSSEN, OOIJEN & STEENHOVEN (2004), who used regression analyses of published experimental data in achieving this. Earlier work by SMITH (1991), on the other hand, used a 3-dimensional finite-element model representing the thermo-physiological system in a non-uniform transient environment where simulations also took into account the air gap between skin and clothing.

It was the work of TOPP, NIELSEN & SORENSEN (2002) in which an accurate geometrical simulation of a nude body in a complex indoor environment was investigated by computational fluid dynamics to objectively determine optimal thermal comfort levels that broke new ground in this field. This was carried further by JACOBSEN, NIELSEN, HANSEN, MATHIESEN & TOPP (2002) who used a 16-component manikin that allowed control of skin temperature to determine such levels in a ventilated room and then by ZHU, KATO & YANG (2007) who devised a non-virtual manikin having the same thermal characteristics of a human body to study its thermal response in various postural and positional conditions when exposed to instantaneous airflows of varying intensity and direction.

On another track are the studies by HUIZENGA, *et al.* (2001) and by ZHANG (2003) in which focus was on the interaction of the human body with its surroundings–as expressed in terms of indices describing a non-uniform transient environment–in order to predict its thermo-response and comfort sensation under various combinations of these. While all the studies mentioned so far dealt with the subject on the basis of a single representative body, the investigation by KANG, XUE & BONG (2001) was unique in that it undertook to model these responses in a non-air-conditioned space with high occupant density to measure levels of thermal stress resulting from heat and moisture released into it over certain lengths of time by the occupants themselves. Though there are other re-ports on similar heat-stress studies (McPHERSON, 1973; ÖNDER, SARAÇ & EREN, 2005; ÖNDER, SARAÇ & ÖNDER, 2005), these are generally confined to extreme environments such as underground shelters.

2.4. REPORTS ON FACTORS, INDICIES AND FORMULATIONS

Being confined to specific and straightforward descriptions/definitions of the various physical phenomena involved in bio-thermal calculations, no need was felt to make discrete distinctions among these as subsections here. Rather, they are loosely ordered according to relative significance in the results obtained from them.

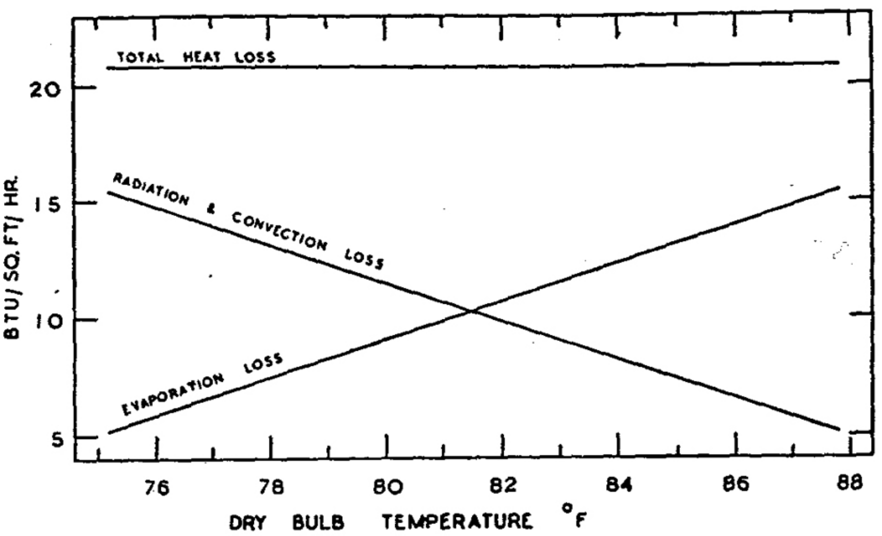
The ***effective temperature index*** combines the effects of indoor phenomena having to do with ambient air–as temperature, humidity and velocity–on the human body that evoke its various responses–both autonomic and behavioral–into a single representative value and is considered by BEDFORD (1974) to be not just an indicator of its thermal comfort sensation, but also to be one that forms the basis of the interrelationship between its heat loss and its surroundings. The illustration of this last aspect by the author, given in Figure 2.8, below, shows that for a constant heat loss from the body, loss by radiation/convection

–a factor excluded from this index–and loss by evaporation have opposite gradients with respect to increasing index values. ASHRAE (1967) also gives credit to the usefulness of this index as a guide in determining comfort levels.

Operative temperature is another index of thermal sensation which this time combines the effects of vapour pressure, air temperature and mean radiant temperature. Obtained from the equation:

$$t_o = (h_r t_{mrt} + h_c t_a)/(h_r + h_c), \quad \text{......................................(2.4)}$$

where h_r is the radiative heat transfer coefficient, t_r is radiant temperature, h_c is convective heat transfer, and t_a is ambient air temperature, it is recommended for use as a practical means of measuring radiative and convective heat losses by ASHRAE (1989).



(temperatures are in degrees Fahrenheit and heat values, in British Thermal Units, BTU)

Figure 2.8. Plot of body heat loss by different channels under various conditions of air temperature and humidity yielding an effective temperature of 75°F (24°C), according to BEDFORD (1974).

Psychrometric parameters, on the other hand, as those aspects of ambient air to which specific values can be ascribed, constitute the quantitative and interactive determinants of its effect on heat exchange processes and, as such, are fully described in the literature by GIVONI (1976), ASHRAE (1989), McPHERSON (1993) and others in terms of their respective contexts. The interaction is graphically depicted by means of a ***psychrometric chart***, an example of which is given from ASHRAE (1989) in Figure 2.9. The elements of this chart consist of both measured and derived indicators; namely, ***dry-bulb temperature***, ***wet-bulb temperature***, ***dew-point temperature***, ***vapour pressure, humidity ratio***, ***relative humidity***, ***sensible heat ratio***, ***specific volume*** and ***enthalpy***, which are so arranged that entering it with any two known ones yields values for the rest at constant sea-level barometric pressure. A schematic version of this chart by McPHERSON (1993), shown in Figure 2.10, following, interprets the meaning of plots beyond a neutral point representing an adiabatic state where there is no warming or cooling effect.

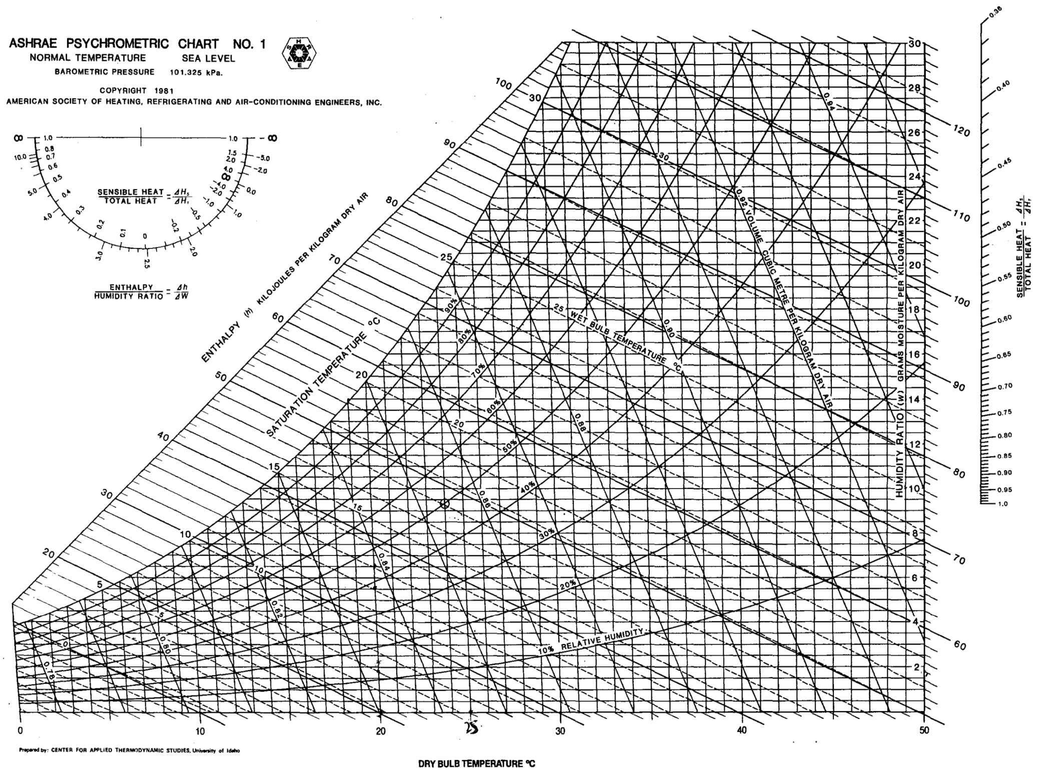


Figure 2.9. The psychrometric chart given by ASHRAE (1989), as prepared by the Center for Thermodynamic Studies, University of Idaho.

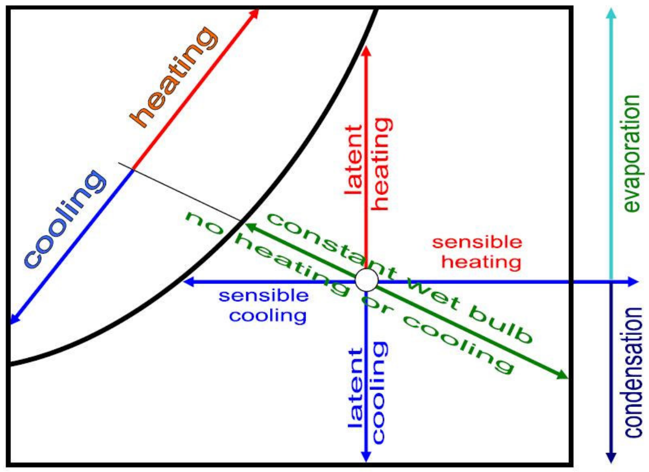


Figure 2.10. Interpretation of the psychrometric chart according to McPHERSON (1993).

The same author goes further to demonstrate some direct effects ensuing from the more well-known of these parameters on mean skin temperature, as shown in Figures 2.11 and 2.12, below, where the former depicts that of dry-bulb temperature on unclothed subjects under conditions of low air velocity and 40% relative humidity and the latter, that of wet-bulb temperature on unclothed, lightly-clothed and fully-clothed subjects.

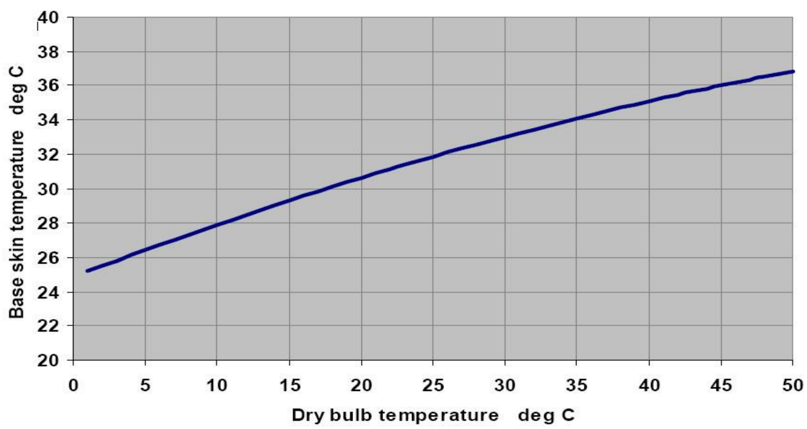


Figure 2.11. Variation of mean skin temperature with dry-bulb temperature for unclothed subjects under conditions of low air velocity and 40% relative humidity, according to McPHERSON (1993).

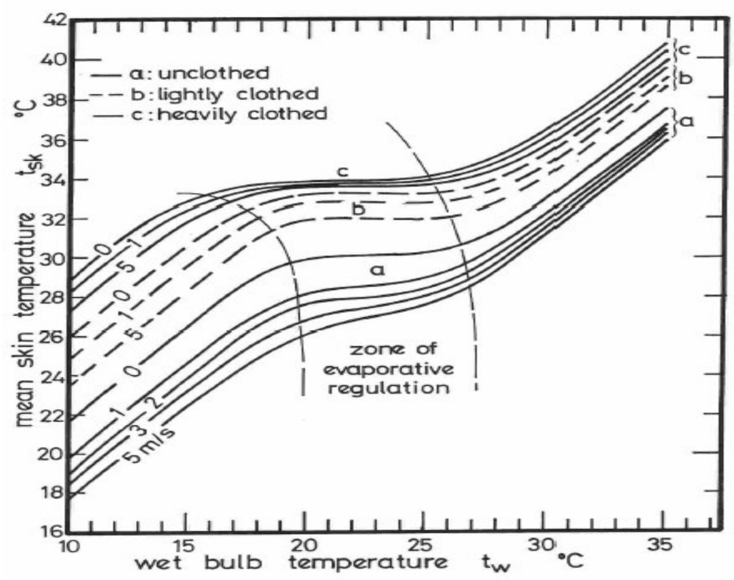


Figure 2.12. Variation of mean skin temperature with wet-bulb temperature for subjects under three different conditions of clothing, according to McPHERSON (1993).

2.5. REPORTS ON METHODOLOGY

Under this section are collected the various calculation methods given in the literature for obtaining quantitative values on aspects pertinent to the subject domain. Being quite extensive, cited here are therefore those deemed most germane in enabling the investigation at hand. As such, they are presented below under 3 sub-sections; namely: methods for integrating external factors with heat balance equations; methods for calculating psychrometric parameters; and methods for calculating the heat load of classrooms.

2.5.1. Methods for integrating external factors with heat balance equations

According to the **one-node energy balance model** proposed by FANGER (1970), all tangible heat, ***M***, produced under **steady state conditions** can be accounted for by the expression, $M = H + W$, where ***H*** is dissipation heat and ***W*** is external work, meaning that the **conductivity** of body layers are ignored and no allowance made for stored heat. These aspects notwithstanding, the author notes that as in this situation the body is near a thermally neutral state at constant body temperature with no autonomic or behavioral regulatory activity, a condition of thermal comfort, where the body surface balances its temperature and moisture levels by way of convection, radiation and evaporation, can be assumed to prevail.

The method in ASHRAE (1989) takes into account both latent and sensible heat losses. It then breaks down each of these into their respective components to express the overall heat loss, $\boldsymbol{W}$, by the equation:

$$M = Q_{sk} + Q_{res} = (C + R + E_{sk}) + (C_{res} + E_{res}), \quad \text{.......................(2.5)}$$

where Q_{sk} is the combined heat loss from the skin and Q_{res} the combined heat loss from respiration, with the former shown to be made up of convective heat loss $\boldsymbol{C}$, radiative heat loss $\boldsymbol{R}$, and evaporative heat loss E_{sk}, while the latter of convective heat loss C_{res} and evaporative heat loss, E_{res}. (Here, C_{res} is called ‘convective’ due to warmer exhaled air being so dissipated within cooler inhaled air.) The combined effect of convective and radiative heat exchange, as loss or gain, is then given by the equation:

$$C + R = (t_{sk} - t_o) / [R_{cl} + 1 / (f_{cl} \times h)], \quad \text{.......................(2.6)}$$

where the first term of the numerator in brackets is skin temperature, t_{sk}, and the second, operative temperature, t_o (though this last is inclusive of mean radiant temperature, it is accepted in practice as equal to air temperature, t_a), $\boldsymbol{h}$ is a heat transfer coefficient defined as the sum of h_r, a constant with a value of 4.70 to account for the black-body effect of radiant heat on the emissivity of clothing and h_c, with a value 3.10 to account for the limiting effect of still air on convective heat, while the remaining terms are as defined in Section 2.2.3.

2.5.2. Methods for calculating psychrometric parameters

The most comprehensive and uniform postulations were found to be in McPHERSON (1993). These were such that nearly all relevant parameters could be derived from a series of interrelated formulations. In this vein:-

Evaporative heat loss from the skin surface, E_{sk}, is given by the equation:

$$E_{sk} = w \times (p_{sk,s} - p_a) / [R_{e,cl} + 1 / (f_{cl} \times h_e)], \quad \text{.....................(2.7)}$$

where w is the skin wetness factor (ranging between 0.6 and 1.0, but usually taken as 0.6 for the 'normal' condition of no sweating); the term of the numerator in brackets is the difference of vapor pressure between the skin, $p_{sk,s}$, and ambient air, p_a, while of the terms in the denominator $R_{e,cl}$ represents the resistance shown by clothing to latent heat transfer from skin to the surroundings with respect to the clothing area ratio, f_{cl}, and h_e refers to evaporative heat transfer coefficient taken as the product of h_c and LR, the Lewis constant already defined earlier.

The partial vapor pressure of ambient air is given in terms of relative humidity, rh, by the equation:

$$rh = e / e_{sd} \times 100, \quad \text{....................................(2.8)}$$

where e is the partial vapor pressure in air and e_{sd} is the saturation water vapour pressure at dry-bulb temperature, t_d, calculated from the equation:

$$e_{sd} = 610.6 \times \exp[17.27 \times t_d / (237.3 + t_d)] \times 10^{-3}, \quad \text{...............(2.9)}$$

while $p_{sk,s}$, assumed to be that of saturated air, is derived by equation:

$$e_{sw} = 610.6 \times \exp[17.27 \times t_w / (237.3 + t_w)] \times 10^{-3}, \quad \text{...............(2.10)}$$

where e_{sw} is the saturation vapour pressure at wet-bulb temperature t_w which, accordingly, skin temperature, t_{sk} is used instead of t_w to calculate $p_{sk,s}$.

Respiratory evaporative heat loss, E_{res}, occurring as it does due to the wetness of the lungs, is calculated from the equation:

$$E_{res} = \dot{m}_{res} \times h_{fg} \times (W_{ex} - W_a) / A_{Du}, \quad \text{...............................(2.11)}$$

where $\dot{m}_{res}$ is pulmonary ventilation rate, which is accepted to be constant as a function of metabolic rate (***M***) under normal conditions where $\dot{m}_{res} = K_{res} \times M$ and K_{res} is a proportionality constant taken as 0.00516; h_{fg} designates latent heat of vaporization of water; the term of the numerator in brackets is the difference of specific humidity between exhaled air, W_{ex}, and inhaled air, W_a.

Latent heat of vaporization of water, ***L***, at dry-bulb temperature, t_d, is then given by the equation:

$$L = 2502.5 - 2.386 \times t_d, \quad \text{(2.12)}$$

where t_{sk} is used instead of t_d to calculate h_{fg}.

Specific humidity of inhaled air, W_a, at standard conditions of 50% rh, 20°C air temperature and sea level barometric pressure is derived by the equation:

$$X = 0.622 \times e / (P - e), \quad \text{(2.13)}$$

where ***X*** refers W_a, which is the actual amount of moisture in ambient air, and ***P*** is barometric pressure at sea level.

The specific humidity of exhaled air, W_{ex}, is nearly 100 % and close to body temperature and is the varies according to W_a and t_a at standard conditions, where $W_{ex} - W_a = 0.0277 + 0.000065 \times t_a - 0.80 \times W_a$

Respiratory sensible heat loss, C_{res}, is the other heat exchange process based on temperature differences between ambient air, t_a, and exhaled air, t_{ex}, which is calculated from the equation:

$$C_{res} = \dot{m}_{res} \times c_{p,a} (t_{ex} - t_a) / A_{Du}, \quad \text{(2.14)}$$

where $c_{p,a}$ designates the specific heat of air, taken at a constant value of 1.01; and t_{ex} is as derived from the formula, $t_{ex} = 32.6 + 0.066 \times t_a + 32 \times W_a$.

2.5.3. Methods for calculating the heat load of classrooms

The subject domain being what it is, the source in this respect is confined to TS 825 (1998) which stipulates that such heat loss, Q, be calculated by the equation:

$$Q = [H_s \times (t_a - t_{ext}) - \eta \times (\phi_i + \phi_s)] \times t, \quad \text{..............................(2.15)}$$

where H_s is the specific heat loss of a building, which indicates thermal insulation performance, as the sum of that by conduction, H_{con}, and that by ventilation, H_v, while t_a and t_{ext} are interior and exterior ambient temperatures, respectively. The equation also takes into account the opposing effect of heat gain, expressed as the factor, η, which consists of mean monthly solar gain, ϕ_s, and mean internal gain from equipment and occupants, ϕ_i, and the last symbol, t, designates time, in seconds.
Conductive heat loss, H_{con}, on the other hand, is calculated by the following equation:

$$H_{con} = \sum A \times U + lU_l, \quad \text{..............................(2.16)}$$

where A is the surface area of building components exposed to lower temperatures, *i.e.*, windows, exterior walls, floor and ceiling; U designates the thermal transmittance of exposed building components, while l is length of thermal bridge and U_l is its linear thermal transmittance. Ventilation heat loss, H_v, is then calculated by the equation:

$$H_v = 0.33 \times n_v \times V_v, \quad \text{..................................(2.17)}$$

where n_v is air change rate, taken as a constant value of 1 for certified window systems and as 2 for others while V_v is ventilated volume, where $V_v = 0.8 \times V_{gross}$.

Interior gain, ϕ_i, is calculated as $5 \times A_n$ for houses, offices, schools, *etc.*, or $10 \times A_n$ for spaces containing industrial equipment that generate heat, where A_n is the net floor area of heated spaces. Solar gain, ϕ_s, on the other hand, is calculated from the equation:

$$\phi_s = \sum r_i \times g_i \times I_i \times A_i, \quad \text{..(2.18)}$$

where r_i is the shading factor for transparent surfaces with a constant value of 0.8 for one- to two-storey detached buildings, 0.6 when the same building is shaded by trees and 0.5 for buildings with more than two storey while g_i, the solar transmission factor of glazing, taken as 0.8$g_\perp$ (transmission at normal incidence) with $g_\perp$ having prescribed values of 0.85, 0.75 and 0.50 for single, clear multiple and shaded glazing, respectively; and I_i is solar radiation incident on vertical surfaces, where the subscript, i, represents orientation. The values of internal and solar gain are decreased by the utilization factor, η, which is calculated from the equation:

$$\eta = 1 - e^{(-1/GLR)}, \quad \text{.......................................(2.19)}$$

where GLR is the gain/loss ratio such that $GLR = (\phi_i + \phi_s) / H \times (t_{in} - t_{ex})$.

2.6. SOURCES FOR OPERATIONAL DATA

These consisted of sources from which operational data on such aspects as school enroll-ment and student composition, classroom configurations and envelope compositions, *et al.* deemed pertinent to the study domain were derived. Thus necessarily being of broad diversity, no need was felt here to make distinction among them under dedicated titles.

A full list of public primary schools falling within the prescribed study area, the Çankaya District of Ankara Province, is given in the records of the MEB District Office. Of the 103 schools on this list registered as being active at this time, only 14 were those put into service after the Integration Act of 1997. Table 2.5 presents those. Being quite extensive as it was, the full list is given in Appendix B.

The source for the architectural drawings of the subject schools was the Head Office of Properties and Infra-structure under the MEB. In the interest of saving on volume, only those for the selected sample–as again defined in Section 3.1–have been provided and then, placed in Appendix C to avoid the extensive interruption of text that would otherwise ensue.

The source for enrolment data on individual schools was the Statistics Department of the MEB Çankaya District Office, which included that for all grade levels, 1 to 8, by gender and by number of sections in each grade. As noted for drawings above, only that for the selected sample has been given under the respective title of Section 3.1.

The most up-to-date data on the basic phsyionomical features of students, as mean body weight and height by gender, was found in the work by NEYZİL, GÜNÖZ, FURMAN, BUNDAK, GÖKÇAY, DARENDELİLER and BAŞ *(*2008). On the other hand, NEBİGİL, HİZEL, TANYER, DALLAR and COŞKUN (1997) had earlier noted the increase in mean weight and height values for each age in comparison to previous measurements. In this vein, NEYZİL, *et al.* (2008) provide what they claim to be a fully updated compilation of growth data for Turkish infants and children between the ages 0 to 18 (given in Appendix D). They also assert that their measurements reflect a new reference for child growth statistics. An abridged list pertaining to the age interval of concern for this study has been given in Section 3.1.2.

Table 2.5 Primary schools in the Çankaya District of Ankara built after 1997

School name	Year Built	Schedule Type	Location
1. Abdurrahman Şengel Primary School	2005	Full time	Dikmen
2. Mehmet Özcan Torunoğlu Primary School	2002	Full time	Oran Sitesi
3. Metin Oktay Mah. Primary School	2002	Full time	Çankaya
4. İl Genel Meclisi Primary School	2001	Full time	Dikmen
5. Misak-ı Milli Primary School	2001	Full time	Beytepe
6. İzzet Latif Aras Primary School	2000	Full time	Dikmen
7. Ayten-Şaban Diri Primary School	1999	Full time	Beysukent
8. Timur Primary School	1999	Full time	Çankaya
9. Ahmet Barındırır Primary School	1998	Full time	100. Yıl Sitesi
10. Büyükhanlı Kardeşler Primary School	1998	Full time	Gazi Osman Paşa
11. Gökçe Karataş İlköğretim Okul	1998	Full time	Dikmen
12. Mehmet Hikmet Ayberk İlköğretim Okulu	1998	Full time	Sepmeevler
13. Türkan Yamantürk Primary School	1998	Full time	Yukarı Ayrancı
14. Türkiye Noterler Birliği Primary School	1998	Full time	Ümitköy

Monthly mean exterior temperatures to be used in calculations for heat loss/gain according to its own stipulations are given in TS 825 (1998). Normative mean interior temperatures for various types of space were found in TS 2164 (1983).

While also given in several other publications, the most pertinent source for data on the thermal and physical properties of construction materials was considered to be TS 825 (1998), as heat loss/gain calculations for classroom envelopes could be directly based on equations provided therein. That on their normative compositions was found to be given by specifications of the MEB Office of Properties.

CHAPTER 3

MATERIAL AND METHOD

In this chapter are presented the material and method used in conducting this investigation. First described is subject material, covering a random sample of schools and germane aspects of their occupants. Derived data is also given under this section. Procedure for sample selection, for calculation of thermal properties pertaining to both environment and occupants and for data evaluation are then described in the section on method.

3.1. MATERIAL

The material used in this study is comprised of data on a sample of 6 primary school buildings located in the Çankaya District of Ankara and pertinent physionomical attributes of Turkish students between the ages of 6 to 14. This data was gleaned from the literature, as cited therein under relevant sections and consisted of:-

- architectural drawings and physical data derived from these;
- enrolment data for the sample schools during the 2007-2008 Academic Year;
- typical U-values of building envelope components for school buildings; and
- physionomical attributes, as weight and height, for the subject student body.

Aspects of these pertinent to the study are collected and described below under two dedicated sub-sections; namely: 3.1.1, Data on sample schools and 3.1.2, Data on the physionomical attributes of the student body.

3.1.1. Data on sample schools

From the 14 defined in Section 2.6, a random sample of 6 schools were selected according to criteria described in Section 3.2.1. As listed in Table 3.1 below, with their year of construction and location, these were then randomly assigned reference designations as S1, S2, S3, S4, S5 and S6 for the sake of maintaining anonymity.

Accordingly, S1, S4, S5 and S6 are comprised of four floors (a basement, a ground floor and two upper floors); S2, of five floors (a basement, a ground floor and three upper floors) and S3 of six floors (two basement levels, a ground floor and three upper floors).

Table 3.1. List of sample schools

School	Date built	Location
S1	2005	Dikmen
S2	2002	Çankaya
S3	2001	Dikmen
S4	2000	Dikmen
S5	1999	Beysukent
S6	1998	100.Yıl sitesi

a) Data on classrooms

Architectural drawings of the sample school buildings were obtained from the source already cited in Section 2.6 and plans of their typical floors are given in Appendix C. These were used to determine classroom sizes, orientations and glazing ratios. Numerical data on school populations were obtained from enrolment registers. It was observed that the planmetric organization of classrooms was almost the same in all 6 schools: double-loaded corridors running in either a North-South or an East-West orientation. This hinted that classrooms would have different heating loads due to their opposing orientations. Quantitative data for the class-rooms derived from the drawings is summarized in Table 3.2 below. Here, the first column lists the sample schools; the second gives the number of classrooms in each; the 3^{rd}, 4^{th}, 5^{th} and 6^{th} columns list the average area, height and volume of these classrooms and their aspect ratios, respectively while the 7^{th} gives window sizes and the last, their glazing-to-wall-area ratios. Of note here is that sample schools embodied different numbers of classrooms.

b) Data on classroom populations:

As obtained from the Çankaya District Office for Public Education, latest available data on school enrolment was accepted. This data is summarized in Table 3.3 below by gender to also show the number of sections allocated to each grade.

Table 3.2. Quantitative data pertaining to classrooms in the six sample school buildings.

School	Classrooms							
	Number of class-rooms	Average area (m^2)	Height (m)	Volume (m^3)	Aspect ratio	Window dimensions (cm)	Average window area (m^2)	Glazing ratio
S1	16	46.6	3.2	745.6	1.10	100 x 75 (4 each)	3	0.14
S2	25	41.3	3.5	1032.5	1.00	110 x 150 (4 each)	6.6	0.31
S3	36	41.1	3.2	1479.6	1.20	100 x 150 (3 each)	4.5	0.24
S4	24	56.8	3.32	1363.2	1.30	150 x 175 (4 each)	10.5	0.41
S5	17	46.5	3.2	790.5	1.10	155 x 170 (3 each)	7.91	0.36
S6	24	46	3.2	1104	1.10	155 x 170 (3 each)	7.91	0.36

Table 3.3. School enrolment by grade and gender, with number of sections per grade.

School	Grade 1			Grade 2			Grade 3			Grade 4		
	B	G	Sec.	B	G	Sec.	B	G	Sec.	B	G	Sec.
S1	35	40	2	36	30	2	36	40	2	26	36	2
S2	61	43	4	58	59	5	42	35	3	30	35	3
S3	52	58	4	71	61	4	79	60	4	67	70	4
S4	59	46	3	66	59	3	67	59	3	45	61	3
S5	48	21	2	39	44	2	41	39	2	42	37	2
S6	53	51	3	54	55	3	50	45	3	52	39	3

School	Grade 5			Grade 6			Grade 7			Grade 8		
	B	G	Sec.	B	G	Sec.	B	G	Sec.	B	G	Sec
S1	19	19	2	22	25	2	32	26	2	20	26	2
S2	47	36	3	45	38	3	27	23	2	17	16	2
S3	74	70	4	90	88	6	102	82	6	62	57	4
S4	53	44	3	69	66	3	65	70	3	78	57	3
S5	48	30	2	55	49	2	63	60	3	48	42	2
S6	50	46	3	65	55	3	56	57	3	60	60	3
B: boys G: girls Sec: sections												

Source: Çankaya District Office of Public Education.

c) Data on building envelope compositions:

The typical classroom used as the basis for calculations was assumed to be located on the ground floor of a 4- to 6-story building with a single exterior-facing wall. For the sake of simplicity, building materials used in the construction of classrooms were assumed to be those specified in the technical handbook for construction (MEB 1998, MEB 2001) and their U-values were defined according to TS 825 (1998). Being needed for heat-load calculations as described under Section 3.2.3, this data is summarized in Table 3.4, following.

Table 3.4. Data on building envelope components and their respective U-values.

Building Component	Description of materials	Thickness d (m)	λh (W/mK)	d/λ. 1/α (m2 K/W)	U – values (W/m^2K)
Exterior Wall	$1/\alpha_i$			0.13	0.44
	Plaster	0.02	0.87	0.023	
	hollow brick	0.19	0.5	0.380	
	Extruded polystyrene foam	0.06	0.04	1.500	
	hollow brick	0.085	0.5	0.170	
	plaster + 3 coats of matt oil paint for h: 1.5m. rest plastic paint	0.02	0.87	0.023	
	$1/\alpha_e$			0.04	
Ground Floor	$1/\alpha_i$			0.17	0.59
	white cement terrazzo tile	0.01	3.5	0.003	
	bedding mortar	0.025	1.4	0.018	
	reinforced concrete deck	0.15	2.1	0.071	
	Slag	0.05	0.045	1.111	
	leveling concrete	0.05	1.4	0.036	
	Waterproofing	0.004	0.19	0.021	
	concrete sub-floor	0.1	1.74	0.057	
	rubble fill	0.15	0.7	0.214	
	$1/\alpha_e$			0	
Window	aluminum framing with heat insulation + double-glazing (4+4)				2.8
$1/\alpha_e$: thermal transmission resistance of exterior face $1/\alpha_i$: thermal transmission resistance of interior face					

3.1.2. Data on the physionomical attributes of students

Only primary school students, grades 1 to 8, ranging from 6 to 14 years of age were included in this study. Physionomical attributes of body weight and height pertaining to this age group was taken from NEYZİL *et al.* (2008) and is summarized in Table 3.5, below.

Table 3.5. Average heights and weights of Turkish children at primary school age (6 to 14).

Age	Average Weight (kg)		Average Height (cm)	
	Boys	Girls	Boys	Girls
6	20.7	20.6	116.1	115.1
7	23.2	22.9	121.5	121.1
8	25.9	25.7	126.9	126.7
9	28.8	28.9	132.1	132.1
10	32.2	32.6	137.6	137.9
11	37.8	38.2	143.8	145.4
12	44.3	45.1	150.6	153.1
13	49.8	50.0	157.7	157.8
14	56.2	53.3	164.9	160.4

Source: Neyzil *et al.* (2008)

3.2. METHOD

The overall method consisted of four discrete phases; namely, sample selection; calculation of sensible heat generated by classroom occupants; calculation of classroom heat loads; and tests of hypotheses. Following are detailed descriptions of each under dedicated sub-sections carrying titles as just given.

3.2.1. Sample selection

Already noted earlier, the initial sample space was defined as public primary schools in the Çankaya District of Ankara. Apart from offering easy access to the author for on-site observations, what underlay this choice was the fact that this happened to be one of the most crowded districts of Ankara where almost all sub-divisions within its administrative boundaries had a similar socio-economic structure and population density. Availability of architectural drawings for the buildings and information pertaining to students in this district was also one of the deciding factors underlying this choice.

Another was rendering its elements as consistent as possible with regard to the tests of hypotheses envisioned. It was thus owing to the fact that, in opposition to private schools, which show large variations in both their layouts and the materials and specifications used in their construction, public schools in Turkey are built according to standard plans and specifications to therefore offer a modicum of the required uniformity that the study was limited to these schools; and then to those located in urban areas, since they were by definition more likely to have larger student bodies than schools in rural ones and so better serve its objectives.

By the same token, when the current state-of-affairs, as stipulated by the Integration Act of 1997, was taken into consideration, the original sample space of 103 schools—as taken from the literature and listed in Appendix B therefrom—was reduced to 14, since it was presumed that only new buildings built after its enactment would be capable of adequately providing the appropriate physical facilities. The size and elements of the sample itself was determined according to the inherent limitations imposed by this reduced space, in conjunction with those by the currency of data on enrolment, the latest of which was for 2007-2008 Academic Year. In this vein, a chronological order based on construction dates, themselves assumed to be random events, was observed such that there would be one from each of the intervening years between 1997 and 2006. Thus it was that the sample came to contain the 6 iterated in Table 3.1.

3.2.2. Calculating sensible heat generated by classroom occupants

Equation 2.5 from ASHRAE (1989), itself based on the one-node energy balance model by Fanger (1970), was used to calculate sensible heat rates from students. This method not only minimized the complexity and the number of variables that would otherwise be involved, but also enabled the researcher to interactively study quantitative values regarding occupants and their surroundings. This also allowed accommodation of factors such as activity and clothing levels, air temperature, relative humidity and air velocity, though this be within its inherent limitations, as explained in Section 2.5.

These limitations necessarily called for certain assumptions to be made regarding both the sample buildings and their occupants. Accordingly:-

- heat gain from occupants was taken as load profiles at hourly intervals;
- occupants in each grade were assumed to be seated uniformly and quietly within their individual classrooms during sessions, which corresponded to sedentary activity under steady-state conditions;

– the effect of acclimatization was ignored and it was assumed that no autonomic thermo-regulatory mechanisms such as sweating were activated;

– occupant attire was assumed to be as described by item 4 of Table 2.3, that is, fitted trousers, long sleeve shirt and suit jacket, giving a thermal resistance, $\boldsymbol{I_{cl}}$, of 0.96 clo;

– metabolic rate per unit body surface area, $\boldsymbol{M/A_{Du}}$, was taken to be 60 W/m^2 as given for the activity defined above in Table 2.4;

– the period to be covered by the investigation was taken as the month of January on the basis of TS 825 (1998), which defines this as being the coldest for Ankara;

– it was assumed that all classrooms were heated but not airconditioned;

– air temperature was taken equal to wall temperature and was assumed to be homogeneous, with no radiant asymmetry or vertical air temperature gradients;

– mean radiant temperature was assumed equal to air temperature;

– air infiltration was assumed present;

– air movement was assumed constant at 0.1 m/s;

– relative humidity was taken as 50%; and

– dry-bulb temperature was assumed constant at 20 ^{o}C .

The calculations based on these assumptions were carried out in three stages. These were as described in the following paragraphs under dedicated headings.

a) Calculations for defining local indices of the thermal environment:

While ASHRAE (1989) provided reliable measured data on sensible and latent heat exchange, these were for American standards of indoor comfort, defined as 24 ^{o}C and 50% relative humidity. As variations in both these parameters affect the level of latent and sensible heat experienced by a body, the values given by this source had to be recalculated for the air temperature of 20 ^{o}C noted above in order to establish compatibility.

To calculate the psychrometric parameters of air, of body skin surface and of pulmonary respiration involved in this, resort was made to equations 2.8, 2.9, 2.10, 2.12 and 2.13, as obtained from McPHERSON (1993). The reason for using this source was that it was clear and detailed as to how psychrometry could be used as an input for the heat balance equation. Although not all these equations were used directly as input data, all were needed for the calculations at one point or another, as outlined in Section 2.5.

b) Calculations for defining the heat balance of occupants:

Radiative, convective and evaporative heat transfer from the clothed body surface was calculated from the heat balance equation cited as equation 2.5 in the literature, the terms of which were found from their respective definitions, again as cited therein, where equation 2.6 was used for convective and radiative heat loss and equation 2.7 for evaporative heat loss from the clothing surface. Equations 2.8, 2.9 and 2.10 were then used to calculate partial pressure in air and on the skin surface, while equation 2.11 was used for evaporative heat loss due to respiration and equations 2.12 and 2.13 were resorted to for the psychrometrics of exhalation, with equation 2.14 being used to calculate sensible heat loss due to this respiration. Here, total heat loss for equation 2.5 was taken as 60 watts per unit body surface area, A_{Du}, as defined by DuBOIS & DuBOIS (1916), which itself was taken as 1.8 m^2 for equations 2.11 and 2.15 and then varied as needed for physionomical differences among the age groups using the method described in ASHRAE (1989). All variables of the heat balance equation were defined in Section 2.5. An explicit listing of these equa-tions, the values of their respective variables and the results found thereby are given in Section 4.1.

c) Calculations for body surface area, A_{Du}, and relative sensible heat rates of classroom occupants:

Physiological basis on heat generation were considered in different way depending on limitations, while in practice most thermal models use a set of physiological data to represent an average person as mentioned in Section 2.2.3. The study itself being based on the one-node model of FANGER (1970), which meant that the skin and the core had to be considered together as one compartment, physiological responses (vaso-motor regulation, pulse rate, sweating) were ignored and heat loss rates were assumed equal to metabolic heat production. Physionomical data for each age, presented in Table 3.5, were therefore used as a passive physiological response to take into account the differences between the amounts of generated heat from occupants of different age groups. In this aspect, the mean weight and height data were used for the calculation of the surface area of students' bodies (A_{Du}) by applying the DuBOIS equation (Eq. 2.1). The derived data, which are listed in Table 4.2, were used to obtain the amount of sensible heat emitted from students at each age by multiplying them with the result from the heat balance equation. Final data is also presented in Table 4.3.

3.2.3. Calculating of classroom heat loads

These loads were calculated for a typical classroom from each sample school according to the procedure described in TS 825 (1998). While the method postulated thereby was for monthly energy needs, results were converted to hourly ones. All classrooms were assumed to be at ground level, to have one exterior wall, to be heated with a hot water system and to have no mechanical ventilation. The ratio of air infiltration was determined on the basis of standard aluminium fenestration. Thermal bridges were neglected and it assumed the buildings themselves were located in areas where there were detached multi storey buildings with no trees shading them. Only basic configurational parameters of the classrooms were used in these calculations. The time of year–necessarily confined to the heating period–was narrowed down to the month of January, stated by this Standard to be the coldest, with a mean temperature of 1.3^{o}C. Co-efficients of thermal transmission (U-values) for building envelope components were also taken from this Standard. Other input data on the thermal environment, such as mean indoor ambient air temperatures and mean internal and solar heat gains were found from equations 2.15, 2.16, 2.17, 2.18 and 2.19 as described in Section 2.2.2.

In keeping with the method prescribed by this Standard–already defined in Section 2.5, and the assumptions above, calculations were conducted in two stages: First were found the heating loads of typical classrooms for each grade in the six samples by integrating sensible heat gains of each grade as internal gain. These were assumed to yield treatment values, the results of which are presented in Section 4.2.1. Then, heating loads for the typical classroom in each of the sample schools were recalculated for three different conditions in order to determine how well treatments could be matched to architectural design strategies. Accordingly:

a) In the first series, all classrooms were assumed to have the same orientation with calculations repeated in turn for major points of the compass as South, East-West and North; all other parameters were identical for each such set where internal heat gain was taken at the standard value of 5W/m^2, mean internal temperature as 20 ^{o}C and U-values as those defined in Table 3.4.

b) A second series of calculations was made assuming a 1°C rise in indoor temperature for the six classrooms with all other factors kept identical to those defined above. In this scenario, all classrooms were south-oriented.

c) In the third series, the total U-value for the exterior wall of each classroom was decreased from 0.44 W/m^{2}K to 0.23 W/m^{2}K by changing its masonry component from hollow brick to AAC (autoclaved ærated concrete) and by increasing the thickness of insulation from 6 to 8 cm, as shown in Figure 3.1 for the 'original' composition and in Figure 3.2 for the altered one, with all other parameters kept identical to those defined for item "a" and orientation as defined for item "b".

Table 4.9 presents the results for the five different treatments of typical classrooms from the six sample schools. It was to these that the statistical tests described in Section 3.2.4, below, were applied. All stages of the calculations involved to this point are explained step by step with an example in Appendix E.

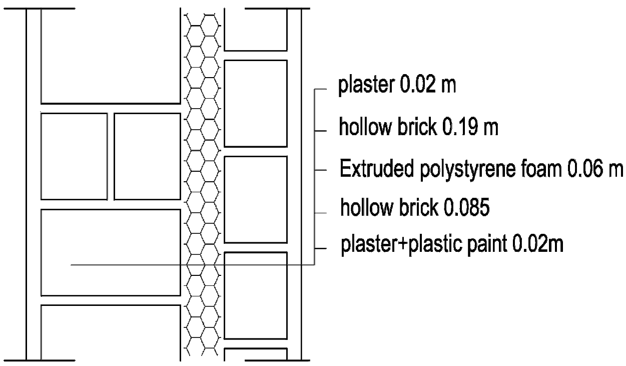


Figure 3.1. Detail of external wall for a composite U-value of 0.44 W/m^{2}K.

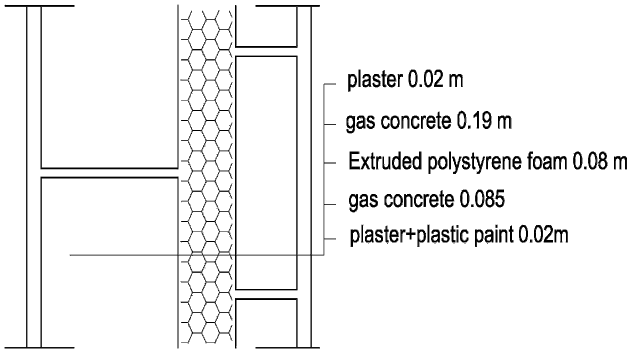


Figure 3.2. Detail of external wall for a composite U-value of 0.23 W/m^{2}K.

3.2.4. Test of hypotheses

Tests of hypotheses were conducted on measured data for heating energy needs of each grade to determine whether or not there were any significant differences among heat gains emitted from occupants with regard to their body sizes. Paired sample *t*-tests at a 5% level of significance were conducted for multiple comparisons based on the null hypotheses, H_o: $\tau_i = 0$, $\mu_1 = \mu_2$, to this end with a two-stage procedure.

In the first, heating energy loads for each grade were individually compared in pairs with those for the other 7. Thus, grade 1 was compared with 7 grades, grade 2 with 6 grades, grade 3 with 5 grades; and so on, yielding a total of 28 pairs to be compared and tested.

In the second, similar paired comparisons were made for the three conditions described under Sub-section 3.2.3, above, on school-by-school basis. This required five discrete sets of tests, one for each of the ensuant alternatives, labelled Q_{south}, $Q_{east\text{-}west}$, Q_{north}, Q 21^{o}C and Q_{better}, respectively.

The analyses were carried out using SPSS 15 software for Windows®. Results of these test are given in Section 4.2.

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter are presented the results of calculations and statistical analyses conducted on derived data, followed by a discussion on their relevance to the study objectives. For clarity, results have been compiled under two sections where the first covers those pertaining to the thermal contribution of classroom occupants and the second, those pertaining to heat load calculations for the 6 classrooms and to the *t*-tests for paired data.

4.1. RESULTS OF INTERNAL HEAT GAIN CALCULATIONS

Below are summarized, in tabular format, the results of calculations for determining the thermal contribution of occupants to the classroom environment. Of these, Table 4.1 has been devised to give a breakdown of the variables and equations used to derive input data for the heat balance equation (eq. 2.5) cited in Section 2.5.

Table 4.1. Derivation of input data for the heat balance equation (eq. 2.5).

Equation No	Ancillary equations $W = Q_{sk}+Q_{res} = (C+R+E_{sk})+(C_{res}+E_{res})$	Variables	Values	Results
2.6	Convective and Radiative heat $C+R = (t_{sk} - t_o) / [R_{cl}+1/(f_{cl} \times h)]$	t_{sk}	30.80	Sensible Heat $Q_S = 45.13$
		t_o	20	
		R_{cl}	0.15	
		$h \times (h_c + h_r)$	3.10 + 4.70	
		f_{cl}	1.23	
2.14	Convective heat from respiration $C_{res} = \dot{m}_{res} \times c_{p,a} \times (t_{ex}-t_a) / A_{Du}$	$c_{p,a}$	1.005	
		t_{ex}	34.15	
		t_a	20	
2.7	Evaporative heat from skin surface $E_{sk} = w \times (p_{sk,s}-p_a)/[R_{e,cl}+1/(f_{cl} \times h_e)]$	w	0.06	Latent Heat $Q_L = 15.15$
		$p_{sk,s}$	4.44	
		p_a	1.17	
		$R_{e,cl}$	0.02	
		h_e	51.15	
2.11	Evaporative heat from respiration $E_{res} = \dot{m}_{res} \times h_{fg} \times (W_{ex}-W_a) / A_{Du}$	m_{res}	0.31	
		h_{fg}	2429	
		W_{ex}	0.03	
		W_a	0.007	
		A_{Du}	1.80	

Column headings being in themselves self-explanatory, it should only be noted here that while most values for the variables were based on the assumptions and delimitations of the study proper, some were necessarily taken from the literature, as cited in Section 2.5. The resultant sensible and latent heat values of the last column were subsequently modified according to the physionomical characteristics of the age groups in question.

The second set of results pertains to the body surface areas of occupants, $\boldsymbol{A_{Du}}$, as derived from equation 2.1. These were calculated separately by gender for each age and then as a mean for each grade, as shown in columns 2, 3 and 6, 7, respectively, of Table 4.2 below.

Table 4.2. Mean surface area values for students in each of the 8 grades.

Age	A_{Du}		Grades	Ages	Mean A_{Du}	
	Boys	Girls			Boys	Girls
6	0.82	0.81				
7	0.89	0.88	1	6-7	0.85	0.84
8	0.96	0.95	2	7-8	0.92	0.92
9	1.03	1.03	3	8-9	0.99	0.99
10	1.12	1.12	4	9-10	1.07	1.08
11	1.23	1.24	5	10-11	1.17	1.18
12	1.36	1.39	6	11-12	1.30	1.32
13	1.48	1.48	7	12-13	1.42	1.44
14	1.61	1.55	8	13-14	1.55	1.51

The last set in this domain pertains to the actual thermal contribution of occupants in each grade. These, derived by multiplying the values under the last column of Table 4.1 with the A_{Du} values for each age in Table 4.2, are given in Table 4.3 by gender, where the first two columns list sensible heat loss, $\boldsymbol{Q_S}$; the next two, latent heat loss, $\boldsymbol{Q_L}$; and the last two, their overall sum.

Table 4.3. Calculated sensible and latent heat loss values.

Grade	Q_S (W)		Q_L (W)		Q_{TOTAL}	
	Boys	Girls	Boys	Girls	Boys	Girls
1	38.43	38.05	12.90	12.77	51.33	50.82
2	41.64	41.34	13.98	13.88	55.62	55.22
3	44.86	44.83	15.06	15.05	59.92	59.87
4	48.43	48.60	16.26	16.31	64.68	64.91
5	52.98	53.37	17.78	17.92	70.76	71.29
6	58.58	59.37	19.66	19.93	78.24	79.30
7	64.21	64.80	21.55	21.75	85.76	86.55
8	69.74	68.37	23.41	22.95	93.15	91.31

4.2 RESULTS OF HEATING LOAD CALCULATIONS

In this section, floor plans of the six typical classrooms and their calculated heating energy loads along with sensible heat gains from each grade are presented. Thereafter, the heating loads of same classrooms from six schools based on different orientations, different indoor temperatures and alternative materials are also given, when internal heat gain was considered to be the standard value of 5 W/m^2 as per TS 825 (1998).

4.2.1 Emitted heat gains

Results of all heating load calculations are presented below in tabulated form for each school. Two sets of calculations were made for each school, one based on actual density of classrooms, Q_0, and the other on the standard predicated density of 1.50 m^2/occupant, Q_1. It was also assumed that classrooms had an equal distribution of occupant gender for both cases.

a) School S1:

With three sizes of marginal difference containing 4 identical windows each, the typical classroom for this school was taken to have an area of 46.6m^2 with an aspect ratio of 1.1 and 4 windows measuring 75 by 100cm, as shown in Figure 4.1, below.

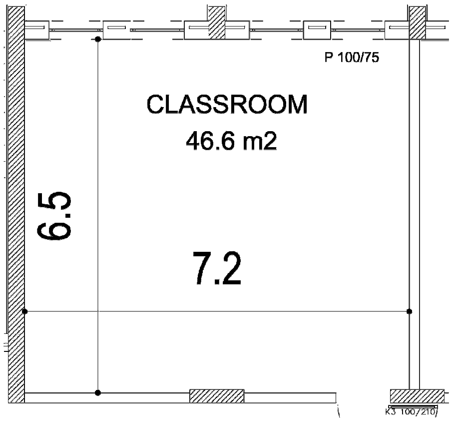


Figure 4.1. Floor plan of the typical classroom in School S1.

The required heating loads calculated for each grade, 1 to 8 are shown in Table 4.4, where the second column gives the actual density of the classroom and the fourth, the predicated one. The third and last columns list the levels of heating energy requirements, Q_0 and Q_1, respectively.

Table 4.4. Heating loads in school S1, by grade, according to actual and normative classroom densities.

Grade	Measured Values		Predicated Values	
	area per student (m^2)	Q_0 (kWh)	area per student (m^2)	Q_1 (kWh)
G 1	1.24	0.45	1.50	0.51
G 2	1.41	0.48		0.50
G 3	1.23	0.43		0.49
G 4	1.50	0.48		0.48
G 5	2.45	0.60		0.48
G 6	1.98	0.54		0.47
G 7	1.61	0.49		0.47
G 8	2.03	0.56		0.47

b) School S2:

There were five sizes of classroom in this school, varying with minor difference from $39m^2$ to $42m^2$, each with four windows. While all windows were of the same height, their widths varied between 109cm and 117cm from one classroom to another. The typical classroom was taken to have an area of 41,3 m^2 with an aspect ratio of 1.0 and to have four windows measuring 110 by 150cm, as shown in Figure 4.2.

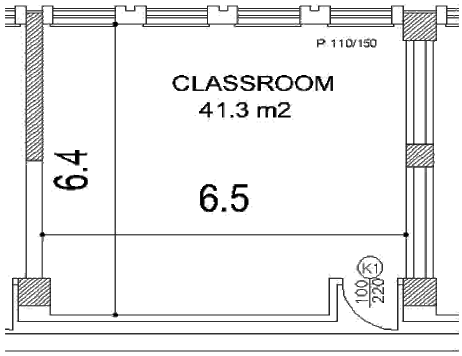


Figure 4.2. Floor plan of the typical classroom in School S2.

The required heating loads calculated for each grade, 1 to 8 are shown in Table 4.5, where the columns list classroom densities and levels of heating energy requirements as described for S1.

Table 4.5. Heating loads in School S2, by grade, according to actual and predicated classroom densities.

Grade	Measured Value		Normalized Values	
	area per student (m^2)	Q_0 (kWh)	area per student (m^2)	Q_1 (kWh)
G 1	1.59	0.62	1.50	0.60
G 2	1.76	0.65		0.59
G 3	1.61	0.61		0.59
G 4	1.91	0.66		0.58
G 5	1.49	0.57		0.57
G 6	1.49	0.56		0.56
G 7	1.65	0.58		0.55
G 8	2.50	0.70		0.55

c) School S3:

While classroom sizes in this school varied between 38m^2 and 50 m^2, all had 4 windows of identical size with corner rooms having an additional 4. The typical classroom was thus taken to have an area of 41.1 m^2 with an aspect ratio of 1.2 and to have 4 windows measuring 100 by 150cm, as shown in Figure 4.3. Classroom densities and the required heating loads for each grade are listed in Table 4.6 along lines described for S1, above.

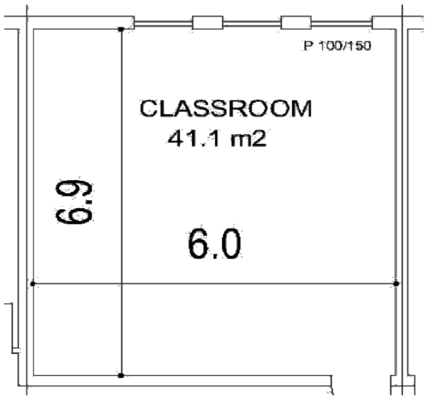


Figure 4.3. Floor plan of the typical classroom in School S3.

Table 4.6. Heating loads in School S3, by grade, according to actual and normative classroom densities.

Grade	Measured Values		Predicated Values	
	area per student (m^2)	Q_0 (kWh)	area per student (m^2)	Q_1 (kWh)
G 1	1.49	0.48	1.50	0.49
G 2	1.25	0.43		0.48
G 3	1.18	0.41		0.48
G 4	1.20	0.41		0.47
G 5	1.14	0.39		0.46
G 6	1.39	0.43		0.45
G 7	1.34	0.42		0.45
G 8	1.38	0.43		0.45

d) School S4:

With six variants ranging from 49m^2 to 56m^2 but all with 4 windows of identical size, the typical classroom for this school was taken to have an area of 50.8 m^2 with an aspect ratio of 1.3. and to have 4 windows measuring 150 by 175cm, as shown in Figure 4.4. Classroom densities and the required heating loads for each grade are listed in Table 4.7, again along lines described for S1, above.

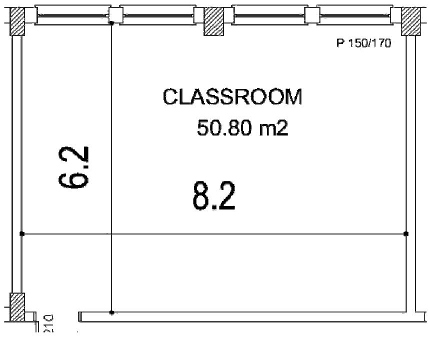


Figure 4.4. Floor plan of the typical classroom in School S4.

Table 4.7. Heating loads in School S4, by grade, according to actual and predicated classroom densities.

Grade	Measured Values		Predicated Values	
	area per student (m^2)	Q_0 (kWh)	area per student (m^2)	Q_1 (kWh)
G 1	1.45	0.75	1.50	0.76
G 2	1.22	0.66		0.75
G 3	1.21	0.65		0.74
G 4	1.44	0.71		0.72
G 5	1.57	0.72		0.71
G 6	1.13	0.58		0.69
G 7	1.13	0.57		0.67
G 8	1.13	0.57		0.67

e) Schools S5 and S6:

As these two schools were identical and had just one size of classroom of 46 m^2 with an aspect ratio of 1.1 and 4 four windows measuring 150 by 175cm each, these were the values taken to define the typical classrooms here, as shown in Figure 4.5. Classroom densities and the required heating loads for each grade are listed in Table 4.8, again along lines described for S1.

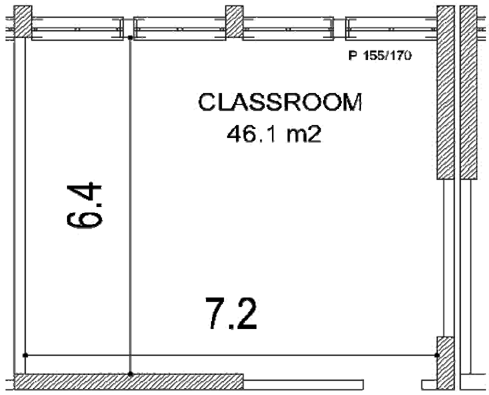


Figure 4.5. Floor plan of typical classrooms for Schools S5 & S6.

Table 4.8. Heating loads in Schools S5 & S6, by grade, according to actual and predicated classroom densities.

Grade	Measured Values		Predicated Values	
	area per student (m^2)	Q_0 (kWh)	area per student (m^2)	Q_1 (kWh)
G 1	1.35	0.58	1.50	0.62
G 2	1.12	0.51		0.61
G 3	1.16	0.52		0.61
G 4	1.18	0.53		0.60
G 5	1.19	0.53		0.59
G 6	0.89	0.42		0.57
G 7	1.13	0.48		0.57
G 8	1.03	0.46		0.56

4.2.2 Standard heat gains

The results of heating load calculations, with classrooms oriented to the south, the east-west and the north, are presented in the second, third and fourth columns of Table 4.9, respectively. The fifth column shows the effect of increasing thermostatic temperature by 1^{o}C on the heating loads of these classrooms combined with that of wall compositions having thermal transmittance (U-values) lowered by thicker insulation.

Table 4.9. Heating load calculations for different parameters in 6 Schools based on 5 W/m^2 internal gains.

School	Q_{south} (kWh)	$Q_{east\text{-}west}$ (kWh)	Q_{north} (kWh)	$Q_{21^{o}C}$ (kWh)	$Q_{U\text{-}value}$ (kWh)
S1	1.01	1.05	1.07	1.08	0.92
S2	1.05	1.14	1.19	1.13	0.97
S3	0.92	0.98	1.01	0.99	0.85
S4	1.30	1.43	1.51	1.40	1.20
S5	1.10	1.20	1.26	1.18	1.02
S6	1.10	1.20	1.26	1.18	1.02

4.3. RESULTS OF STATISTICAL TESTS

Of the 28 pairs in the first stage, the *t*-test could not be applied to pair 1 as the standard error of its differences was zero. The results of these tests are presented in Table F.1 in Appendix F.

These results indicated that differences between grades were statistically significant ($p< 0.05$) for all pairs. The hypothesis, H_0, was therefore rejected at the 5% level of significance. More explicitly, it was seen that grade 1 was significantly different from grades 3, 4, 5, 6, 7 and 8; that grade 2 was significantly different from grades 3, 4, 5, 6, 7 and 8; that grade 3 was significantly different from grades 4, 5, 6, 7, and 8; that grade 4 was significantly different from grades 5, 6, 7 and 8; that grade 5 was significantly different from grades 6, 7 and 8; that grade 6 was significantly different from grades 7 and 8; and that grade7 was significantly different from grade 8.

For the second stage of the investigation, use was made of the values listed Table 4.9. This table, comprising the three factors noted in Sub-section 4.2.2 gives heating load levels calculated for the five different alternative conditions defined thereby for the classrooms of the six sample schools on an hourly basis.

Here, the heating load for Q_{south} was compared with the other 4, so that there were a total of 4 pairs to be compared and tested against the null hypothesis. As the results of these tests, given in Table F.2, showed that differences between levels of heating requirements were statistically significant ($p<0.05$) for all pairs, the null hypothesis was rejected at the

5% level of significance. What this was taken to mean was that Q_{south} was significantly different from $Q_{east\text{-}west}$, Q_{nourth}, Q 21°C and Q_{better}.

When the mean values of these 5 heating levels, shown in Table F.3 with their descriptive statistics, were compared and their differences interpreted, it was found that:-

– a north orientation required approximately 0.13 kW more energy per hour to maintain the classroom at 20°C than does a south one;

– an east-west orientation required approximately 0.08 kW more energy per hour to maintain the classroom 20°C than does south one;

– for a south orientation, approximately 0.08 kW more energy was needed per hour to maintain a 1 degree increase in classroom temperature from 20°C to 21°C; and

– the wall composition with a lowered thermal transmission co-efficient provided a reduction of approximately 0,09 kW per hour in the energy needed to maintain the classroom at 20 °C.

These marginal values were taken to indicate that there were no meaningful benefits to be gained from any such design modifications in comparison to the order of magnitude seen in the differences between the mean values for the grades themselves, as given in Table F.4 with their descriptive statistics.

4.4. DISCUSSION

Issue of the derived data was the total heat loss rates related to surface area of the bodies, where those were assumed also to refer to total heat production of the students. To check the accuracy of these data, a list of metabolic rates on the basis of body weight were compiled from DURNIN (1981). The table covers three age groups arranged with regard to their weights as 0-9, 10-18, and over 18, as shown in Appendix G. For consistency, the unit of basal metabolic rate given thereby was converted from kilocalories (kcal) per day; to watts (W) per hour. The data for the first and second groups were used for comparison in graphic form, as presented in Figure 4.6 for boys and in Figure 4.7 for girls.

Three curves were compared, which were DURNIN's (1981) data on basal metabolic rate (BMR); calculated data of total metabolic heat production (derived by multiplying the A_{Du} surface area of each age group by 60 W/m^2); and calculated data of sensible heat load for each age (obtained from heat balance equation results). All of these calculated values, *i.e.* metabolic heat and sensible heat, are given in Table 4.3. The important quality was the ‘trend’ of the three variables when compared with each other rather than the presence of any 'similarity' among them. Basal metabolic rate is the minimum energy required for living, whereas total metabolic heat production depends on posture, on work performed and on body movements, as well as on the basal energy of the human body.

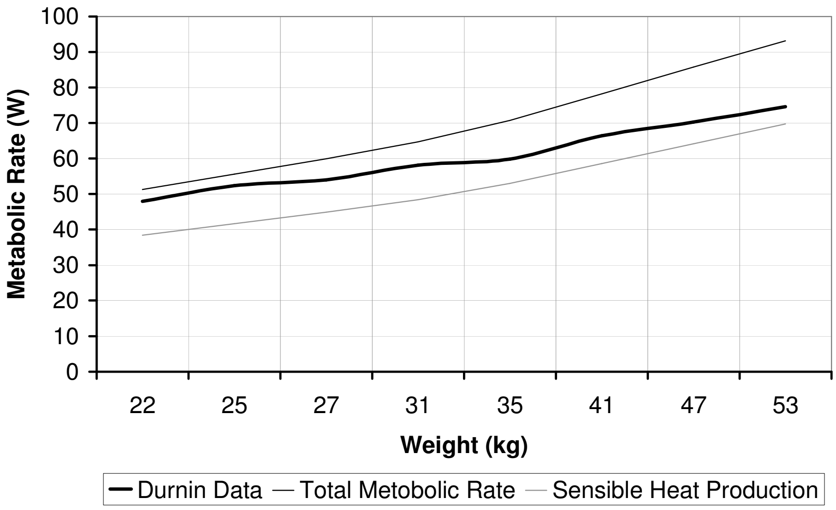


Figure 4.6. Comparison of data on basal metabolic rate with measured metabolic heat production for boys.

In the comparative graph with the BMR results of DURNIN (1981) shown in Figures 4.6 and 4.7, the rate of increase was higher than that for DURNIN’s (1981) data for both, especially after 3rd grade, Consequently, the result of the higher metabolic rate for higher grades may cause much higher internal gains, which may in turn decrease the energy requirement levels.

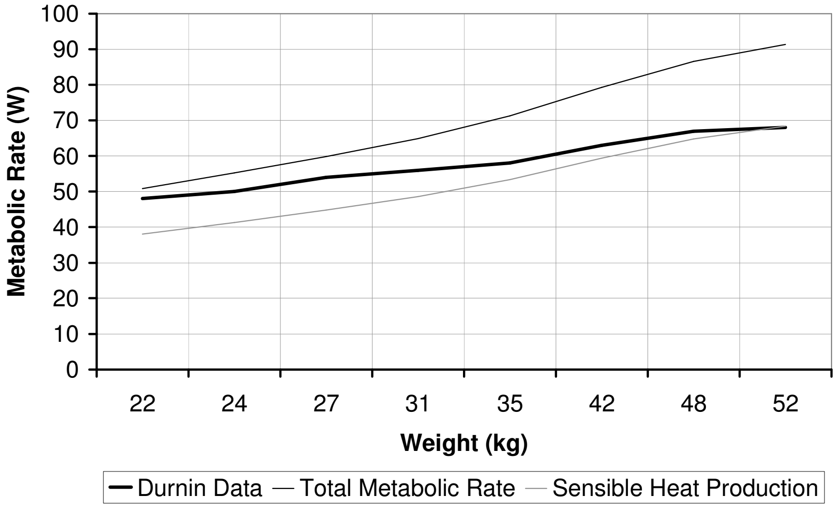


Figure 4.7. Comparison of data on basal metabolic rate with measured metabolic heat production for girls.

CHAPTER 5

CONCLUSION

School building requires distinct approaches than the other type of buildings. Especially, primary school architecture is as crucial as the education to support student performance and well being, in terms of that it comprises the developmental age of students from 6 to 14. Other than wide range of occupant profile, school buildings has crowded spaces and also that student's working places are varied depending on their lectures, such as; while classrooms have uniformly dense occupancy, laboratories and workshop spaces have variable occupancies. Therefore, their activity levels and thus comfort conditions are varied. Furthermore, the reason of heat loads from students by emitted heat and moisture from their bodies in a crowded space, regarding to having no air-conditioning, thermal comfort studies for school buildings get more important.

The other aspect of comfort studies is to support energy efficiencies within limitation of quality conditions. Simulation of energy profile and investigation of energy saving strategies of school buildings by national surveys are important to improve their energy performance. It is possible to use various methods for studies of comfort parameters or energy conservation techniques for that. In this context, the studies on school buildings in Turkey from the literature survey conducted were varied depending on their limitations and assumptions. This research focused on some aspects of human bio-thermal properties, with the objectives explained in Section 1.2. Questions guided the research, and to achieve some answers of the questions which parameters had to be taken as constant and which had to be variable were discussed in order to determine the method. The main question was constituted on whether different surface area of students related to different age groups in the primary schools was effective on heating loads in the classrooms.

Previous studies about human thermoregulation system and its response to environment were overviewed to choose an applicable method. Most models served specific purposes, not able to function for all conditions. On the other hand, whole body models requires large amount of data that is not possible to attain accurate results because of complex thermo-physiology of human and also body shape. Therefore accuracy of models depends on their limitations.

It was another issue to consider that the existing values assume an average man. To be able to differ the heat emitted from the students' bodies depending on their age groups, height and weight values of them were considered as the variance of calculations, since development of children bodies between the ages 6 to 14 can be explained by these two indices as a reference for each age group. In this context, heat balance equation belonging to FANGER (1970) was applied considering the directions of ASHRAE (1989). Hence, other physiological parameters were ignored, and physionomical data for each age were therefore used as a passive physiological response to take into account the differences between the amounts of generated heat from students of different age groups. Heat transfer theory according to this equation was based on sensible and latent heat exchange from clothing surface of the body and during the respiration within its limitations. Accordingly, the rate of sensible and latent heat was calculated. Thereafter, the result was varied by DuBOIS surface area of the body sizes of students. Each sensible heat value of each grade was integrated to heating load measurement method of TS 825 (1998) as an internal heat gain. Output data after some adjustments were compared by paired sample t-test.

Because of the method of this investigation, two aspects for thermal comfort studies, either the effects of occupant or typologies and structural characteristics on heating energy profiles of school buildings, were considered. Although this study illustrates the importance of interrelation of occupant with its thermal environment, one was taken into consideration more that how emitted temperature from human body affects on heating load of classrooms by a comparison method between the grades regarding to main question mentioned above.

According to age-related results from t-test presented in Section 4.3, all of paired grades had differences at 5% level of significance. The differences determined by statistical methods did not support the notion that all paired grades could benefit from architectural intervention. To convert the statistical inferences to architectural meaning, three main parameters were determined such as direction of windows, indoor temperature, and U-values of building components, and heating load level of six typical classrooms for each parameter were calculated. The mean values of results were compared with each other to get their quantity differences. Thereafter, these differences were matched with the differences of mean values between the grades to get the answer. As a result, any beneficial differences between the grades according to the alternative designing parameters, depending on limitations and adjustments, were not obtained to benefit for public primary schools in Çankaya. However, calculation of emitted sensible heat from students shows that 5 W/m^2, which is standard internal heat gain from occupants determined in TS 825, is not enough value for classrooms. This difference was considerable for its effects on the result of the heating energy needs.

Another point conducted on envelope quality and orientation of classrooms, the results shows their importance on heating load level. First each typical classroom was assessed with 3 orientations. Here was the important point is the glazing ratio. Because the type of glazing, the area of glazing, the direction the glazing faces and the placement of any shading either influence the amount of solar gain, or support day lighting for educational performance, whereas it causes the heat loss from envelope. The results show the south oriented classroom requires less energy to heating the classroom than other directions, about % 12.66 less than north and about % 8.03 less than east-west oriented classrooms. These results show the south direction is the best way for conservation of heating energy. However Ankara climate is in the third zone from four climatic zones in Turkey according to TS 825, which means that it has hot summer and cold winter. Hence during the summer solar gain can cause discomfort in classrooms and cooling strategies can required.

Other point is the typologies of classrooms in selected schools; they were a linear alignment of classes on both sides of corridor, which means they are oriented opposite direction. Therefore, for the optimum solution for comfort conditions, typology of classrooms, their orientations and glazing ratio should be considered together for both summer and winter period. Other consideration was the envelope properties of classrooms. As a wall material, hollow brick is used. Decreasing U- value of exterior wall by improving thermal insulation and changing wall material results in decrease energy consumption by % 7.71. The last parameter was conducted to understand that how much energy was required for change of a 1 ^{o}C in indoor temperature. The result indicated about % 7.41 more energy need to heating up.

The other outcome of this investigation was about renovated standards of primary school buildings. The introduction of eight year education gave new challenges to primary schools, such as; ending unified class applications, getting through from binary education to normal education, increasing the number of classrooms and respectively reducing the number of students. However, literature survey shows that the schools built after 1998 does not reflect all these requirements of today. Accordingly, the collecting data of enrolments and classroom size of selected schools confirmed that the level of student density of classrooms was not equal for all and did not reflect required condition. Therefore, it was obliged to normalize the area per student for calculations.

It must be noted that this research was based on the rate of sensible heat loads only, whereas the effect of moisture generated by evaporation from the students should also be considered, especially, on the basis of density levels of classrooms. Additionally, this analysis was based on one hour heat loads only; therefore, when the whole day is taken into account, transient periods may influence the results differently. Furthermore, thermo-physical properties of classrooms were optimized instead of as-built properties for determining heating load. Other than heating load levels, surface temperature levels of walls were also accepted as equal to ambient temperatures, which would affect the amount of radiative heat loss from students.

Almost all present studies about human thermal responses are supported by empirical method of thermal comfort studies. Within the scope of this investigation, many restrictions guided the analysis and a field study was not possible to match the analysis results. In this regard, the results should be confirmed by a field work for future works. Moreover, consideration of the issue of mean radiant temperature in detail can be beneficial for comfort studies in school building Turkey. Because, it is possible to see that much of the educational investments have continued with typical project applications though Turkey has different climatic and geographical characteristics. Accordingly the thermal performance of wall construction is weak, which causes temperature differences between wall inside surface and ambient air, then it cause heat loss from body surface by radiative way. This can increase to feel thermally discomfort whereas ambient temperature is between in comfort range.

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APPENDIX A

TYPICAL METABOLIC HEAT GENERATION FOR VARIOUS ACTIVITIES ACCORDING TO ASHRAE (1989)

Table A.

	W/m^2	met[b]
Resting		
Sleeping	40	0.7
Reclining	45	0.8
Seated, quiet	60	1.0
Standing, relaxed	70	1.2
Walking (on the level)		
0.89 m/s	115	2.0
1.34 m/s	150	2.6
1.79 m/s	220	3.8
Office Activities		
Reading, seated	55	1.0
Writing	60	1.0
Typing	65	1.1
Filing, seated	70	1.2
Filing, standing	80	1.4
Walking about	100	1.7
Lifting/packing	120	2.1
Driving/Flying		
Car	60–115	1.0–2.0
Aircraft, routine	70	1.2
Aircraft, instrument landing	105	1.8
Aircraft, combat	140	2.4
Heavy vehicle	185	3.2
Miscellaneous Occupational Activities		
Cooking	95–115	1.6–2.0
House cleaning	115–200	2.0–3.4
Seated, heavy limb movement	130	2.2
Machine work		
sawing (table saw)	105	1.8
light (electrical industry)	115–140	2.0–2.4
heavy	235	4.0
Handling 50-kg bags	235	4.0
Pick and shovel work	235–280	4.0–4.8
Miscellaneous Leisure Activities		
Dancing, social	140–255	2.4–4.4
Calisthenics/exercise	175–235	3.0–4.0
Tennis, singles	210–270	3.6–4.0
Basketball	290–440	5.0–7.6
Wrestling, competitive	410–505	7.0–8.7

APPENDIX B

COMPLETE LISTING OF PRIMARY SCHOOLS IN THE ÇANKAYA DISTRICT.

Table B.

SCHOOLS	COMMISSIONING DATES
1. Fatma-Yaşar Önen Primary School	1965
2. Pakize Erdoğu Primary School	1988
3. Gökay Primary School	1990
4. Ahmet Bahadır İlhan Primary School	1989
5. Eşref Bitlis Primary School	1992
6. Kütükçü Alibey Primary School	1975
7. Kıymet Necip Tesal Primary School	1990
8. Talatpaşa Primary School	1970
9. Süleyman Uyar Primary School	1991
10. Ahmet Andiçen Primary School	1991
11. Kılıçali Paşa Primary School	1992
12. Akşemsettin Primary School	1971
13. Milli Eğitim Vakfı Primary School	1989
14. Ahmet Yesevi Primary School	1986
15. Ahmet Haşim Primary School	1993
16. Turhan Feyzioğlu Primary School	1993
17. Seyranbağları Primary School	1963
18. Hamdullah Suphi Primary School	1966
19. Dedeman Primary School	1989
20. Gülten Kösemen Primary School	1961
21. Kemal Atatürk Primary School	1967
22. Mehmet İçkale Primary School	1993
23. Ahmet Vefik Paşa Primary School	1968
24. Tevfik İleri Primary School	1945
25. Kurtuluş Primary School	1929
26. Ülkü Akın Primary School	1994
27. Bademlidere Primary School	1979
28. Boztepe Primary School	1978
29. Çankaya Primary School	1929
30. Yücetepe Primary School	1961
31. Milli Egemenlik Primary School	1983
32. Ayten Tekışık Primary School	1974
33. Bahçelievler Nebahat Keskin İlköğretim Ok.	1938
34. Maltepe Primary School	1954
35. Dr.Reşit Galip Primary School	1967

Table B, continued

36. Atasülün Primary School	1979
37. Mimar Kemal Primary School	1927
38. Muazzez Karaçay Primary School	1993
39. Gaziosmanpaşa Necla-İlhan İpekçi İ.Ö.O	1966
40. Türkan Yamantürk Primary School	1998
41. İncesu Primary School	1953
42. Teğmen Kalmaz Primary School	1964
43. Anıttepe Primary School	1952
44. Beytepe Primary School	1983
45. Mimar Sinan Primary School	1972
46. Mithatpaşa Primary School	1952
47. Nurçin Sayan Primary School	1964
48. Timur Primary School	1999
49. Rauf Orbay Primary School	1986
50. Şahinbey Primary School	1959
51. Sokullu Mehmet Paşa Primary School	1957
52. Halide Edip Adıvar Primary School	1966
53. Kavaklıdere Primary School	1954
54. Dikmen Öğretmen Necla Kızılbağ Primary School	1962
55. Salih Alptekin Primary School	1971
56. İltekin Primary School	1929
57. Yasemin Karakaya Primary School	1994
58. Namık Kemal Primary School	1950
59. Mustafa Kemal Primary School	1966
60. Kırkkonaklar İffet Güneşoğlu İlköğretim Ok	1970
61. Türk-İş Blokları Primary School	1977
62. Nenehatun Primary School	1968
63. Ulubatlı Hasan Primary School	1953
64. Özyurt Primary School	1974
65. İzciler Primary School	1986
66. Hürriyet Primary School	1962
67. Hasan Özbay Primary School	1967
68. Mohaç Primary School	1968
69. Akpınar Primary School	1980
70. Ertuğrulgazi Primary School	1962
71. Reşatbey Primary School	1968
72. Alparslan Primary School	1962
73. Mehmet Hikmet Ayberk Primary School	1998
74. Fahri Çaldağ Primary School	1968
75. Sarar Primary School	1944
76. 27 Aralık Lions Primary School	1970
77. Gülen Muharrem Pakoğlu Primary School	1966
78. Erdoğan Şahinoğlu Primary School	1995
79. Ziraat Mühendisleri Primary School	1996
80. Arjantin Primary School	1968
81. Yenilik Primary School	1983

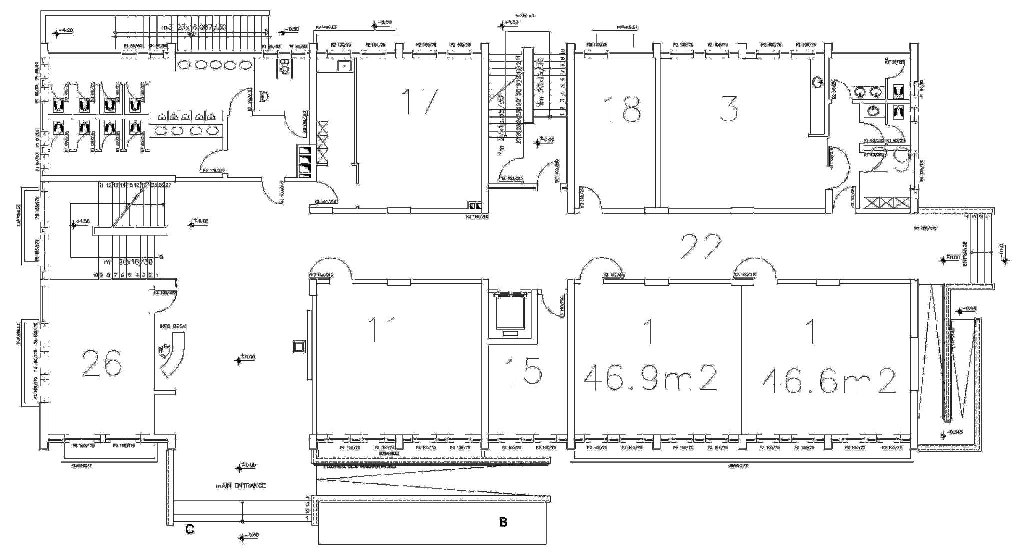
Table B, continued

82. DSİ.Primary School	1987
83. T Emlak Bankası Primary School	1996
84. Bilgi Primary School	1982
85. Hüseyin Hüsnü Tekışık Primary School	1981
86. Köy Hizmetleri Primary School	1989
87. Cebesoy Primary School	1968
88. Aşağı İmrahor Primary School	1946
89. Karataş Primary School	1981
90. Yeşilkent Primary School	1966
91. Or-An Perihan İnan Primary School	1972
92. Özbirlik Primary School	1987
93. Türkiye Noterler Birliği Primary School	1998
94. Ahmet Barındırır Primary School	1998
95. Büyükhanlı Kardeşler Primary School	1998
96. Gökçe Karataş Primary School	1998
97. Ayten-Şaban Diri Primary School	1999
98. İzzet Latif Aras Primary School	2000
99. İl Genel Meclisi Primary School	2001
100. Misak-ı Milli Primary School	2001
101. Metin Oktay Mah.Primary School	2002
102. Mehmet Özcan Torunoğlu Primary School	2002
103. Abdurrahman Şengel Primary School	2005

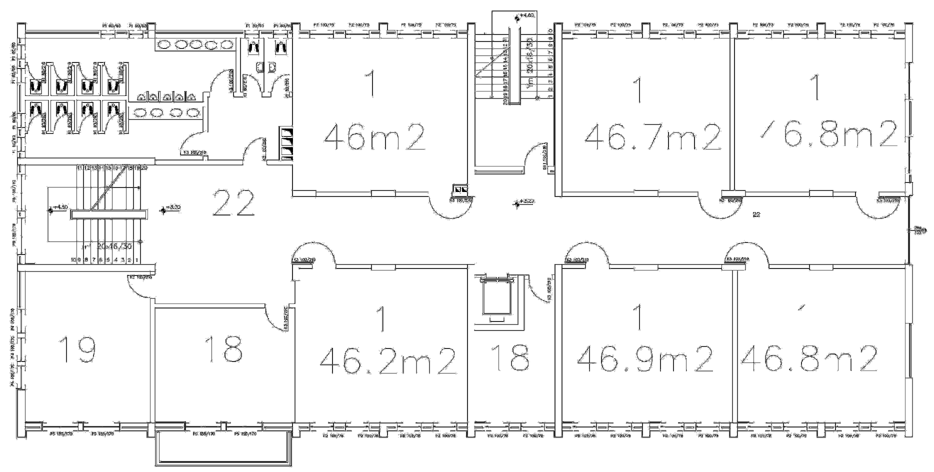
Source: Department of Statistics, MEB Çankaya District Office of Public Education,

APPENDIX C

ARCHITECTURAL DRAWINGS OF PRIMARY SCHOOLS IN THE STUDY SAMPLE



GROUND FLOOR



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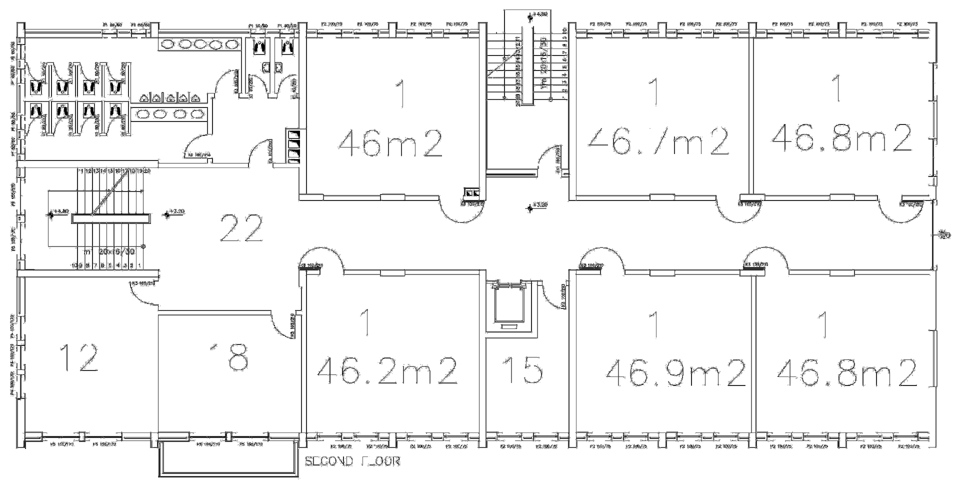
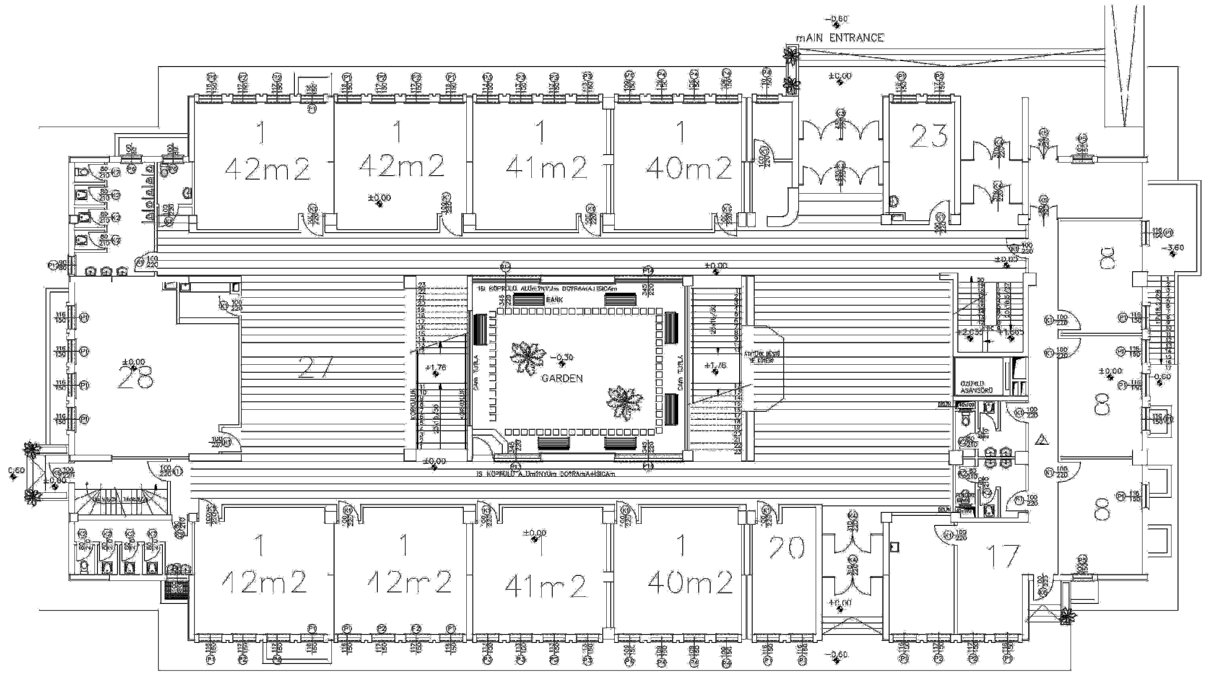


SECOND FLOOR

1-Classroom 2- Prep. Class 3- Kindergarten 4- Music Room 5- Art Room 6- Lab. 7- Studio 8- Activity Space 9- News Rom 10- Science Lab. 11- Computer Applications 12- Library 13- Multipurpose Hall 14- Gymnasium 15- Guidance 16- Parent-Teacher Association 17- Staffroom 18- Office 19- Principle 20- Co-director 21- Lounge 22- Hall 23- Health Centre 24- Instrument Stock 25- Book Stock 26-Archive 27- Playground 28- Canteen 29- Depot 30- Heating Centre 31- Asylum

Figure C.1. School S1



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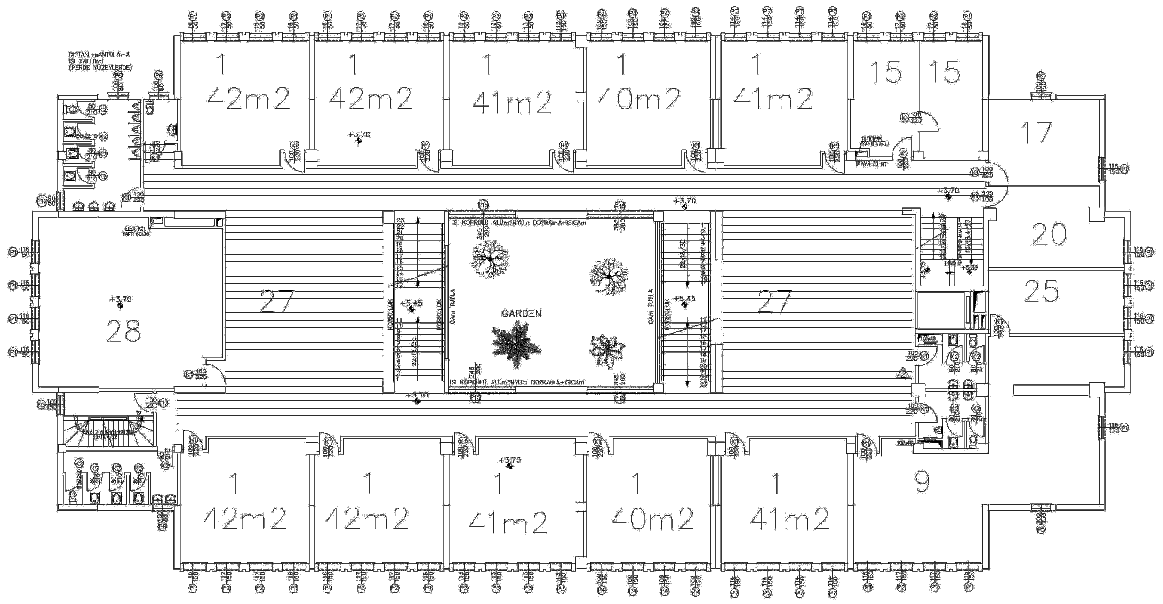

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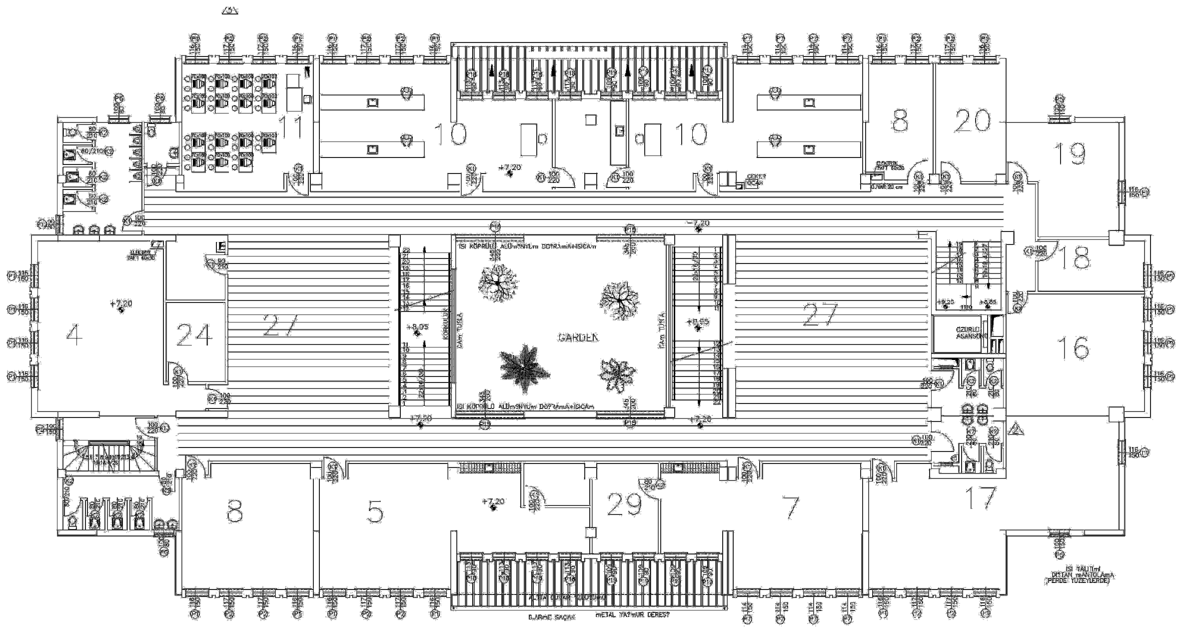

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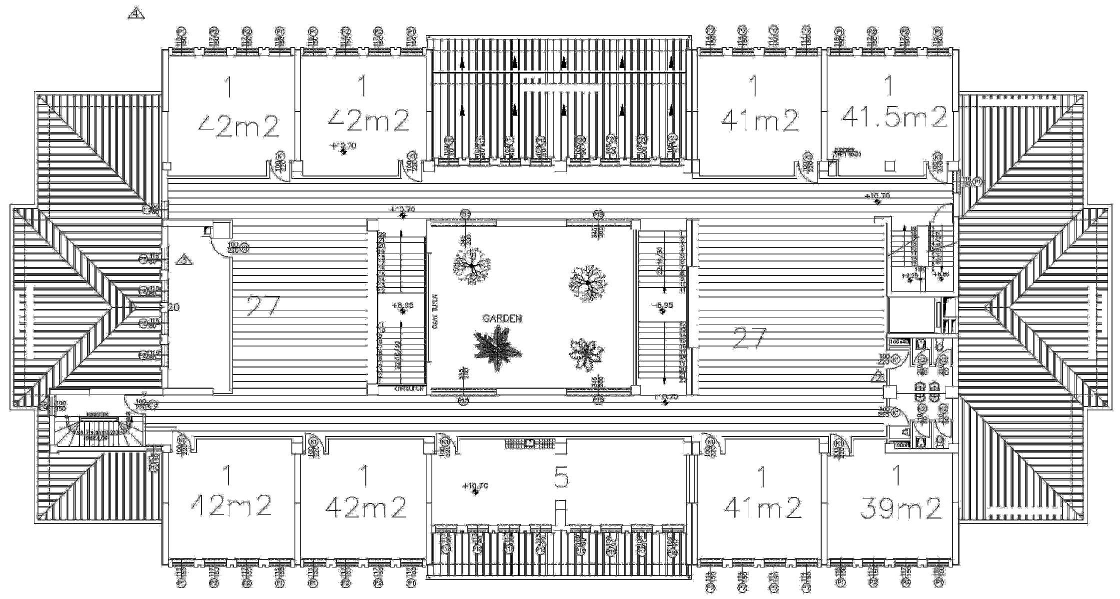
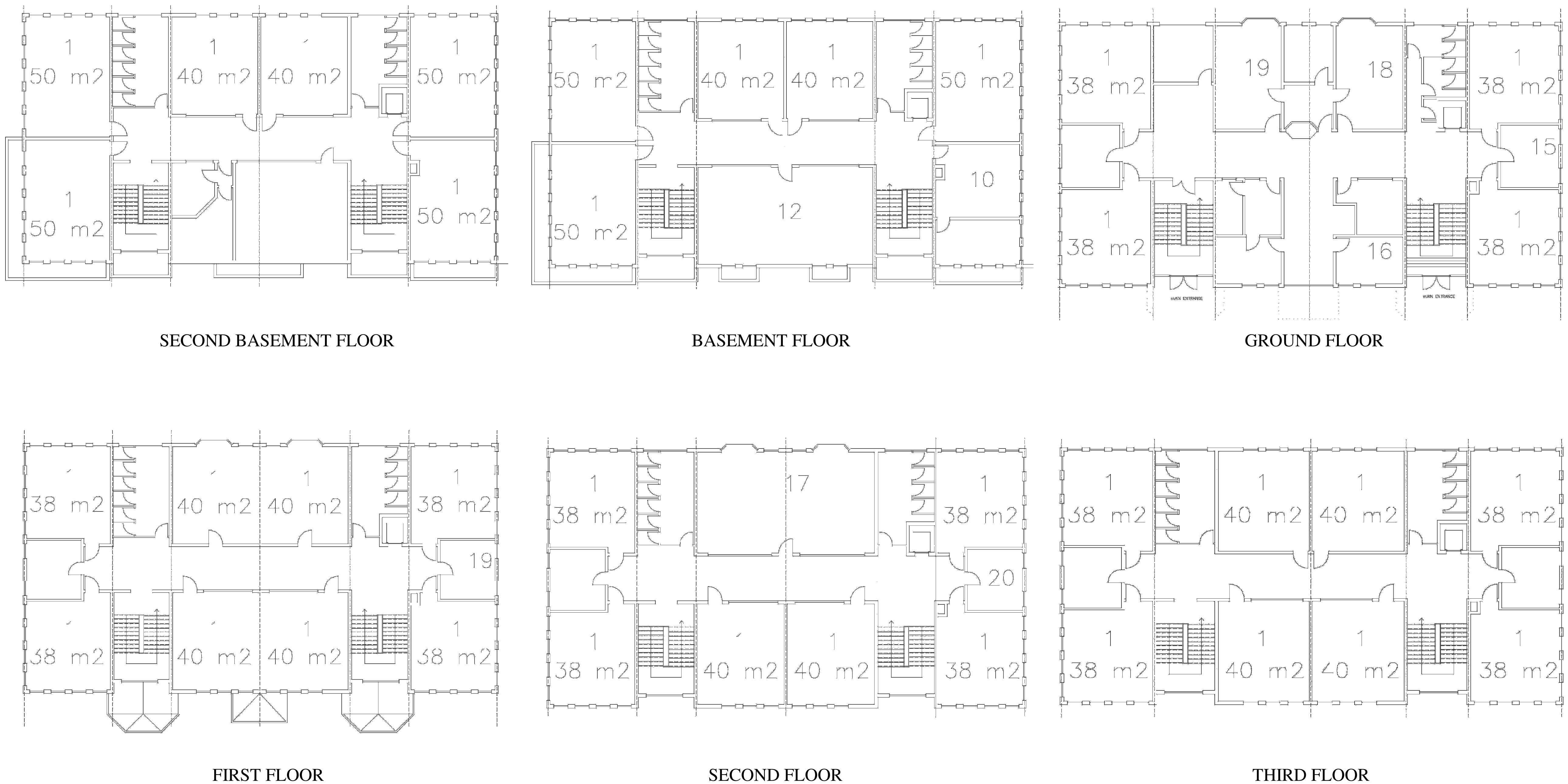


THIRD FLOOR

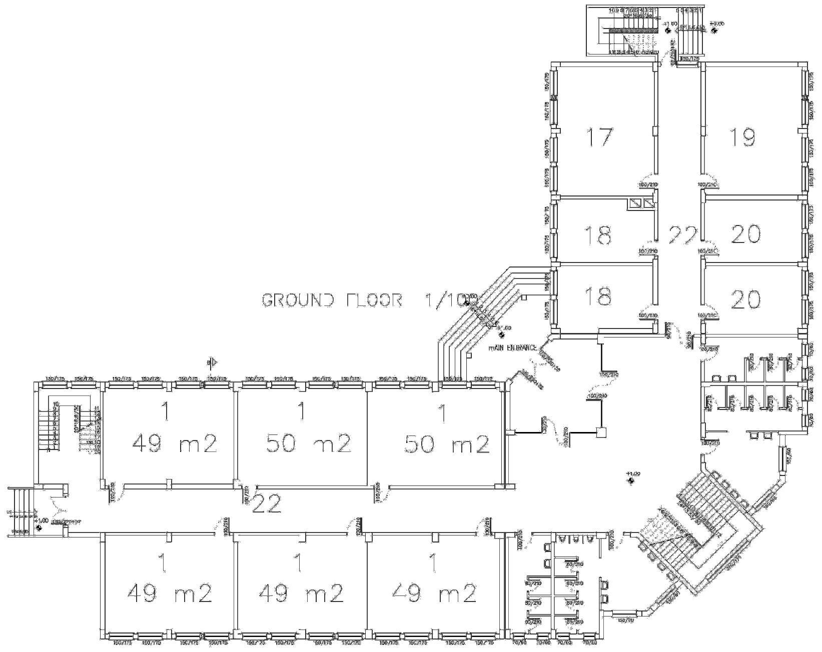
1-Classroom 2- Prep. Class 3- Kindergarten 4- Music Room 5- Art Room 6- Lab. 7- Studio 8- Activity Space 9- News Rom 10- Science Lab. 11- Computer Applications 12- Library 13- Multipurpose Hall 14- Gymnasium 15- Guidance 16- Parent-Teacher Association 17- Staffroom 18- Office 19- Principle 20- Co-director 21- Lounge 22- Hall 23- Health Centre 24- Instrument Stock 25- Book Stock 26-Archive 27- Playground 28- Canteen 29- Depot 30- Heating Centre 31- Asylum

Figure C.2. School S2

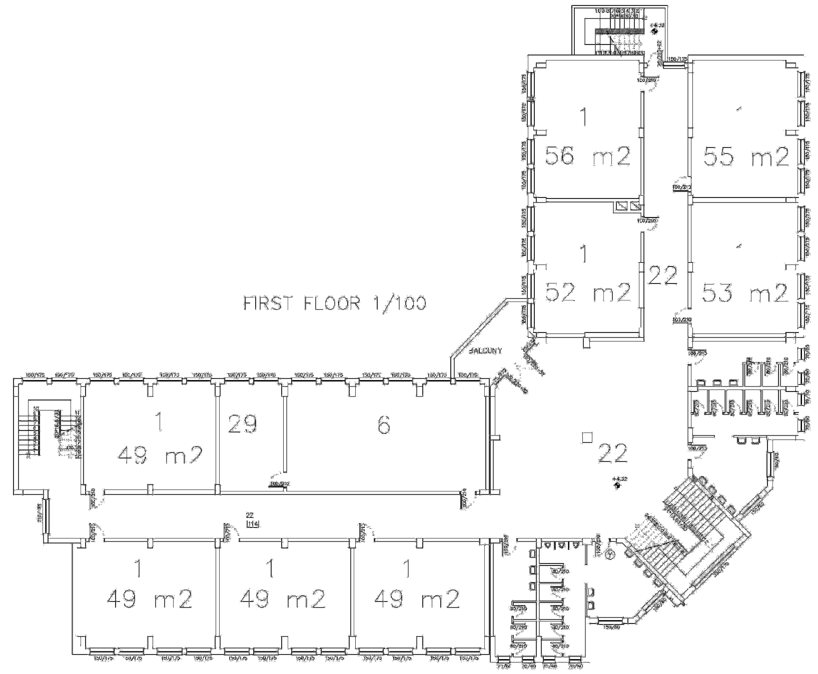


1-Classroom 2- Prep. Class 3- Kindergarten 4- Music Room 5- Art Room 6- Lab. 7- Studio 8- Activity Space 9- News Rom 10- Science Lab. 11- Computer Applications 12- Library 13- Multipurpose Hall 14- Gymnasium 15- Guidance 16- Parent-Teacher Association 17- Staffroom 18- Office 19- Principle 20- Co-director 21- Lounge 22- Hall 23- Health Centre 24- Instrument Stock 25- Book Stock 26-Archive 27- Playground 28- Canteen 29- Depot 30- Heating Centre 31- Asylum

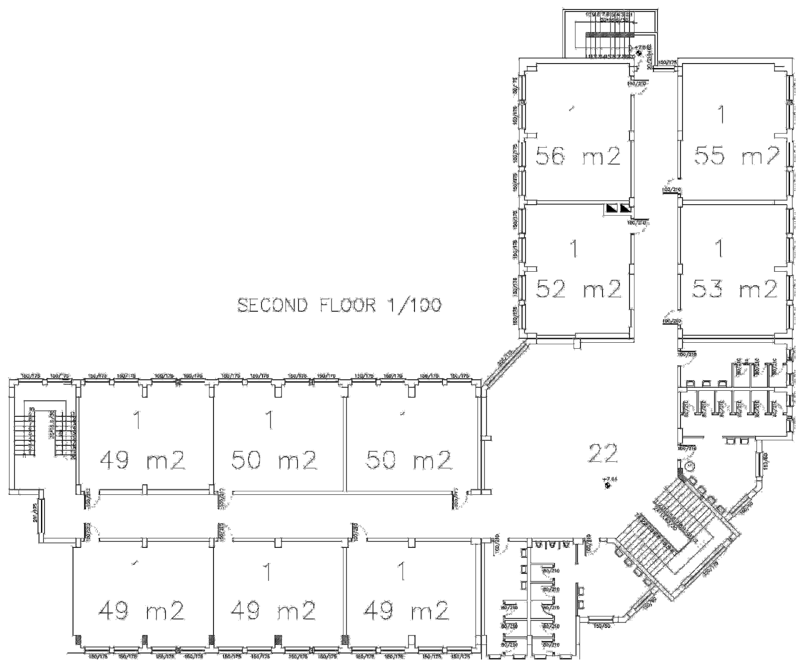
Figure C.3. School S3



GROUND FLOOR



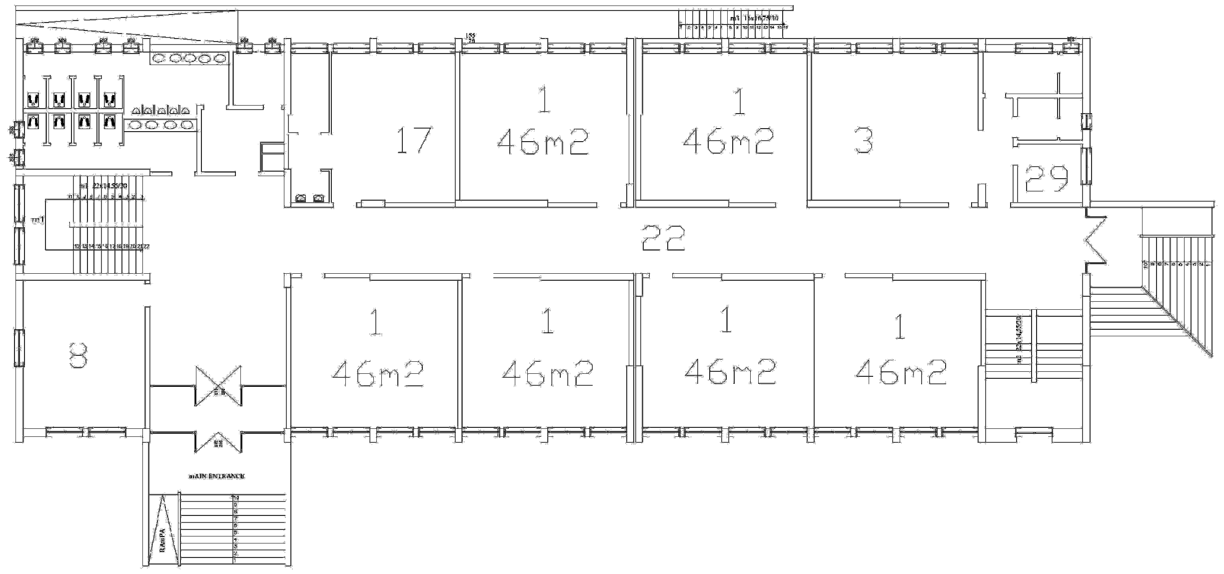
FIRST FLOOR



SECOND FLOOR

1-Classroom 2- Prep. Class 3- Kindergarten 4- Music Room 5- Art Room 6- Lab. 7- Studio 8- Activity Space 9- News Rom 10- Science Lab. 11- Computer Applications 12- Library 13- Multipurpose Hall 14- Gymnasium 15- Guidance 16- Parent-Teacher Association 17- Staffroom 18- Office 19- Principle 20- Co-director 21- Lounge 22- Hall 23- Health Centre 24- Instrument Stock 25- Book Stock 26-Archive 27- Playground 28- Canteen 29- Depot 30- Heating Centre 31- Asylum

Figure C.4. School S4



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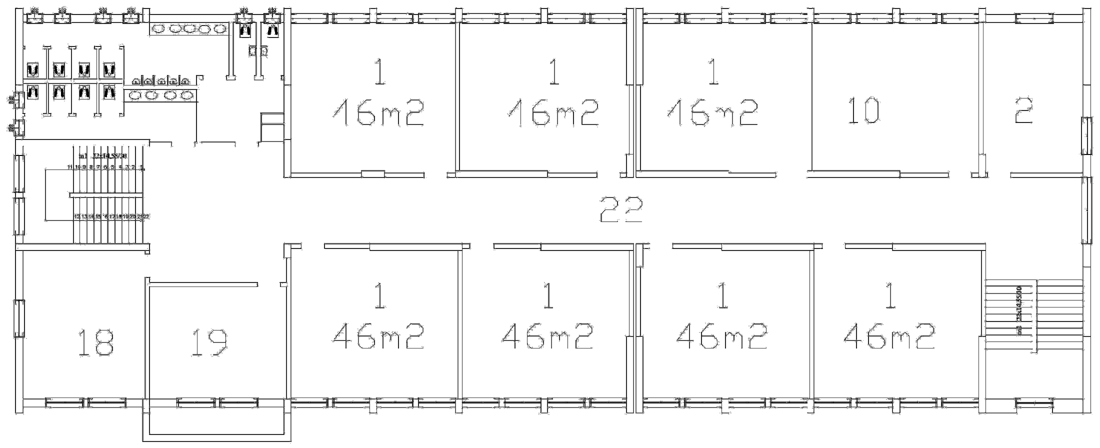
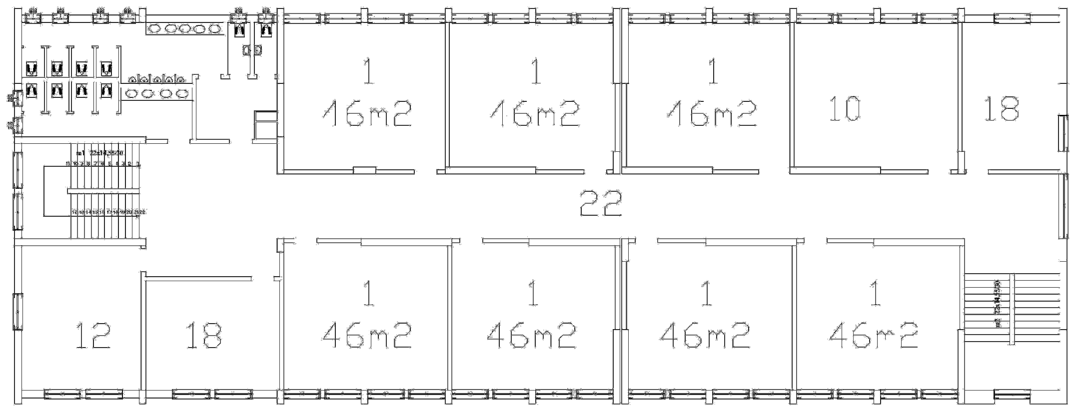


FIRST FLOOR



SECOND FLOOR

1-Classroom 2- Prep. Class 3- Kindergarten 4- Music Room 5- Art Room 6- Lab. 7- Studio 8- Activity Space 9- News Rom 10- Science Lab. 11- Computer Applications 12- Library 13- Multipurpose Hall 14- Gymnasium 15- Guidance 16- Parent-Teacher Association 17- Staffroom 18- Office 19- Principle 20- Co-director 21- Lounge 22- Hall 23- Health Centre 24- Instrument Stock 25- Book Stock 26-Archive 27- Playground 28- Canteen 29- Depot 30- Heating Centre 31- Asylum

Figure C.5. School S5 & School S6

APPENDIX D

ANTHROPOMETRIC DATA

Table D.1. Percentile values of weight for Turkish children aged 0 to 18 y. according to Neyzil e*t al*. (2008)

Erkek								Kız						
3	10	25	50	75	90	97	Yaş	3	10	25	50	75	90	97
2.58	2.85	3.13	3.43	3.73	4.00	4.27	Doğum	2.52	2.76	3.01	3.29	3.58	3.84	4.10
4.75	5.26	5.79	6.38	6.99	7.54	8.10	3 ay	4.48	4.90	5.33	5.82	6.32	6.78	7.24
6.21	6.79	7.41	8.12	8.85	9.54	10.25	6 ay	5.94	6.38	6.85	7.43	8.06	8.68	9.34
7.27	7.87	8.51	9.26	10.06	10.81	11.58	9 ay	6.85	7.34	7.89	8.55	9.29	10.02	10.82
7.96	8.61	9.32	10.16	11.05	11.92	12.82	12 ay	7.52	8.06	8.66	9.39	10.20	11.00	11.87
8.61	9.28	10.01	10.89	11.83	12.75	13.72	15 ay	8.09	8.67	9.31	10.10	10.96	11.81	12.73
9.13	9.82	10.58	11.49	12.48	13.46	14.49	18 ay	8.57	9.19	9.87	10.71	11.63	12.55	13.54
10.12	10.85	11.66	12.66	13.76	14.86	16.05	2 yaş	9.49	10.20	10.99	11.94	12.99	14.03	15.15
11.06	11.84	12.71	13.80	15.04	16.29	17.69	2.5 yaş	10.35	11.17	12.06	13.12	14.25	15.33	16.47
11.81	12.65	13.61	14.83	16.24	17.71	19.39	3 yaş	11.19	12.09	13.05	14.18	15.37	16.51	17.68
12.6	13.5	14.6	15.9	17.4	18.9	20.6	3.5 yaş	11.9	12.8	13.9	15.1	16.5	17.8	19.3
13.3	14.3	15.4	16.8	18.5	20.1	22.0	4 yaş	12.7	13.7	14.8	16.1	17.7	19.2	20.8
14.0	15.0	16.2	17.7	19.5	21.3	23.3	4.5 yaş	13.5	14.5	15.8	17.3	19.0	20.7	22.5
14.7	15.8	17.0	18.6	20.5	22.4	24.6	5 yaş	14.2	15.4	16.7	18.4	20.3	22.2	24.3
15.4	16.5	17.9	19.6	21.6	23.6	26.0	5.5 yaş	14.9	16.2	17.7	19.5	21.6	23.7	26.1
16.2	17.4	18.9	20.7	22.8	25.1	27.7	6 yaş	15.7	17.0	18.6	20.6	22.9	25.3	27.9
18.1	19.5	21.1	23.2	25.8	28.5	31.6	7 yaş	17.2	18.7	20.6	22.9	25.7	28.6	31.9
19.9	21.5	23.4	25.9	28.9	32.2	36.1	8 yaş	18.9	20.8	22.9	25.7	28.9	32.4	36.5
21.7	23.6	25.8	28.8	32.4	36.4	41.3	9 yaş	20.9	23.1	25.6	28.9	32.8	37.0	41.8
23.6	25.9	28.6	32.2	36.7	41.6	47.8	10 yaş	23.0	25.6	28.7	32.6	37.3	42.3	48.0
26.6	29.6	33.1	37.8	43.6	50.0	57.8	11 yaş	26.4	29.6	33.4	38.2	43.7	49.5	55.9
29.9	33.8	38.4	44.3	51.3	58.7	67.1	12 yaş	32.0	35.8	39.9	45.1	50.9	56.8	63.1
33.4	38.0	43.2	49.8	57.3	64.9	73.3	13 yaş	37.4	41.1	45.1	50.0	55.5	60.8	66.6
39.1	44.0	49.4	56.2	63.9	71.6	80.1	14 yaş	41.6	45.0	48.8	53.3	58.3	63.2	68.5
45.3	50.1	55.4	62.1	69.7	77.4	85.9	15 yaş	44.0	47.3	50.9	55.3	60.1	64.8	69.8
49.9	54.5	59.7	66.2	73.6	81.2	89.6	16 yaş	45.3	48.5	52.0	56.3	61.0	65.7	70.7
53.2	57.8	62.8	69.2	76.5	84.0	92.4	17 yaş	46.2	49.4	52.9	57.2	61.8	66.4	71.4
56.1	60.5	65.5	71.8	79.0	86.4	94.7	18 yaş	47.3	50.5	53.9	58.1	62.2	67.3	72.2

Table D.2. Percentile values of height for Turkish children aged 0 to 18, according to Neyzil *et al.* (2008)

Erkek								Kız						
3	10	25	50	75	90	97	Yaş	3	10	25	50	75	90	97
45.9	47.2	48.5	50.0	51.5	52.9	54.2	Doğum	45.3	46.6	47.9	49.4	50.8	52.1	53.4
56.2	57.8	59.5	61.3	63.2	64.8	66.4	3 ay	55.3	56.8	58.2	59.9	61.5	63.0	64.5
62.8	64.5	66.2	68.0	69.9	71.6	73.2	6 ay	61.6	63.1	64.7	66.4	68.2	69.7	71.3
67.4	69.1	70.9	72.8	74.7	76.4	78.1	9 ay	66.0	67.7	69.3	71.2	73.0	74.6	76.3
70.8	72.7	74.7	76.9	79.1	81.1	83.0	12 ay	69.7	71.4	73.2	75.1	77.1	78.8	80.5
73.8	75.8	77.9	80.2	82.5	84.5	86.6	15 ay	72.8	74.6	76.5	78.5	80.6	82.4	84.2
76.4	78.5	80.7	83.1	85.5	87.7	89.8	18 ay	75.5	77.4	79.3	81.5	83.7	85.6	87.6
81.0	83.3	85.6	88.2	90.8	93.2	95.5	2 yaş	80.1	82.3	84.4	86.8	89.2	91.4	93.5
85.3	87.6	90.0	92.6	95.3	97.6	100.0	2.5 yaş	84.0	86.3	88.6	91.2	93.8	96.1	98.4
89.3	91.7	94.1	96.8	99.4	101.8	104.2	3 yaş	87.8	90.2	92.7	95.4	98.1	100.6	103.0
92.8	95.2	97.7	100.5	103.2	105.7	108.2	3.5 yaş	91.1	93.6	96.2	99.0	101.9	104.5	107.0
96.0	98.6	101.1	104.0	106.9	109.5	112.0	4 yaş	94.3	96.9	99.6	102.5	105.5	108.1	110.7
99.0	101.7	104.3	107.3	110.3	113.0	115.6	4.5 yaş	97.4	100.1	102.8	105.9	108.9	111.6	114.3
101.8	104.5	107.3	110.4	113.5	116.2	119.0	5 yaş	100.4	103.2	105.9	109.1	112.2	114.9	117.7
104.5	107.3	110.1	113.3	116.4	119.3	122.1	5.5 yaş	103.6	106.3	109.0	112.1	115.3	118.3	121.2
107.1	110.0	112.9	116.1	119.3	122.2	125.1	6 yaş	106.2	109.0	111.9	115.1	118.4	121.3	124.1
112.1	115.1	118.2	121.5	124.9	128.0	131.0	7 yaş	111.6	114.6	117.7	121.1	124.4	127.5	130.5
116.9	120.0	123.3	126.9	130.5	133.7	136.9	8 yaş	116.7	119.9	123.1	126.7	130.3	133.5	136.7
121.6	124.9	128.3	132.1	135.9	139.3	142.7	9 yaş	121.3	124.7	128.2	132.1	136.0	139.5	142.9
126.4	130.0	133.6	137.6	141.6	145.2	148.7	10 yaş	125.8	129.6	133.5	137.9	142.2	146.1	150.0
131.7	135.5	139.4	143.8	148.1	152.0	155.9	11 yaş	132.5	136.6	140.8	145.4	150.1	154.2	158.3
137.0	141.3	145.7	150.6	155.4	159.8	164.1	12 yaş	141.1	144.9	148.8	153.1	157.4	161.2	165.1
142.8	147.6	152.4	157.7	163.1	167.9	172.6	13 yaş	146.6	150.2	153.8	157.8	161.8	165.5	169.0
150.3	155.0	159.7	164.9	170.1	174.8	179.5	14 yaş	149.3	152.8	156.4	160.4	164.3	167.9	171.4
156.9	161.2	165.5	170.3	175.1	179.4	183.7	15 yaş	150.7	154.2	157.8	161.7	165.7	169.3	172.8
160.9	164.9	168.9	173.4	177.9	181.9	185.9	16 yaş	151.3	154.8	158.4	162.4	166.3	169.9	173.4
163.0	166.8	170.7	175.0	179.3	183.2	187.1	17 yaş	151.7	155.2	158.8	162.7	166.7	170.3	173.8
164.5	168.2	172.0	176.2	180.4	184.2	187.9	18 yaş	152.0	155.6	159.1	163.1	167.1	170.7	174.2

APPENDIX E

AN EXAMPLE OF CALCULATIONS

Energy Balance Equation

$M = Q_{sk} + Q_{res} = (C + R + E_{sk}) + (C_{res} + E_{res})$ W/m^2, ... (2.5)

where

$M =$ 60 W/m^2 activity level Table 2.4.

hence

$(C + R + E_{sk}) + (C_{res} + E_{res}) =$ 60 W/m^2

$C+R = (t_{sk} - t_o) / (R_{cl} + 1 / (f_{cl} x\ h))$ W/m^2, convective and radiative heat loss, ………..(2.6)

where

$t_{sk} =$ 30.80 ^{o}C it was determined by adjusting it to equalize the values of heat loss and heat production

$t_o = (h_r t_{mrt} + h_c t_a)/(h_r + h_c) =$ 20 ^{o}C operative temperature because of $t_{mrt} = t_a$, ……. (2.4)

$t_a =$ 20 ^{o}C

$R_{cl} = k\ I_{cl.} =$ 0.15 (m^2 x ^{o}C)/W clothing insulation

$I_{cl} =$ 0.96 clo clothing insulation for fitted trousers, long-sleeve shirt and suit jacket from Table 2.3

$k =$ 0.155 (m^2 x ^{o}C)/(clo x W) unit conversion factor

$f_{cl} =$ 1.23 clothing area factor Table 2.3

$h = h_c + h_r =$ 7.80 W/(m^2 x ^{o}C) combined heat transfer coefficient

$h_c =$ 3.1 W/(m^2 x ^{o}C) nearly constant for still air (0.1 m/s)

$h_r =$ 4.7 W/(m^2 x ^{o}C) nearly constant for black body effect of clothing at typical indoor temperatures

hence

$C+R =$ 42.68 W/m^2

$E_{sk} = w \times (p_{sk,s} - p_a) / [R_{e,cl} + 1 / (f_{cl} \times h_e)]$ W/m^2, evaporative heat loss from skin , … (2.7)

where

$w =$ 0.06 the fraction of wetted skin surface

$p_a = e = e_{sd} \cdot \times rh / 100 =$ 1.17 kPa partial pressure of water vapour in the ambient air, ……………………………………………………………....(2.8)

$rh =$ 50 % relative humidity

$e_{sd} = 610.6 \exp[17.27 \times t_d / (237.3 + t_d)] \times 10^{-3} =$ 2.34 kPa saturation water vapour pressure, ………………………………………………………………… (2.9)

$t_d =$ 20 °C dry-bulb temperature

$p_{sk,s} = e_{sw} = 610.6 \times \exp[17.27 \times t_{sk} / (237.3 + t_{sk})] \times 10^{-3} =$ 4.44 kPa vapour pressure at t_{sk}, ……………………………………………………………… (2.10)

$R_{e,cl} = R_{cl} / i_{cl} \times LR =$ 0.02 (m^2 x kPa)/W evaporative heat transfer resistance at clothing Surface, ……………………………………………..…………………(2.2)

$i_{cl} =$ 0.45 as a constant if no data are available

$LR =$ 16.50 K/kPa The Lewis Relation at standard conditions

$h_e = LR \times h_c =$ 51.15 W/(m^2 x kPa) convective evaporative heat transfer resistance at clothing surface

hence

$E_{sk} =$ 5.46 W/m^2

$E_{res} = \dot{m}_{res} \times h_{fg} \times (W_{ex} - W_a) / A_{Du}$ W/m^2 evaporative heat loss from respiration, ……(2.11)

where

$\dot{m}_{res} = K_{res} \times M =$ 0.31 kg/s pulmonary ventilation rate

$K_{res} =$ 0.00516 (kg x m^2)/kJ proportionality constant

$h_{fg} = L = 2502.5 - 2.386 \times t_{sk} =$ 2429 kJ/kg latent heat of vaporization of water at t_{sk}, ……………………………….…………………………………..(2.12)

$W_{ex} = 0.0277 + 0.000065 \times t_a + 0.20 \times W_a =$ 0.03 specific humidity of exhaled air

$W_a = X = 0.622 \times e / (P-e) =$ 0.007 specific humidity of inhaled air (ambient air), ... (2.13)

$e = p_a$

$P =$ 101.3 kPa barometric pressure at sea level

$A_{Du} = (wg^{0.42} \times hg^{0.725}) \times 71.84 = 1.8$ m^2 DuBois surface area of the body, …..………(2.1)

$wg =$ 70 kg $hg =$ 1.73 cm average man from ASHRAE

hence

$E_{res} =$ 9.69 W/m^2

$\boldsymbol{C_{res}} = \boldsymbol{\dot{m}_{res} \times c_{p,a} (t_{ex} - t_a) / A_{Du}}$ W/m^2 convective heat loss from respiration, ………… (2.14)

where

$\boldsymbol{c_{p,a}} =$ 1.005 kJ/(kg x °C) specific heat of air.

$\boldsymbol{t_{ex}} = \boldsymbol{32.6 + 0.066t_a + 32W_a} =$ 34.15 °C temperature of exhaled air

hence

$\boldsymbol{C_{res}} =$ 2.45 W/m^2

results

$\boldsymbol{Q_S} = \boldsymbol{C + R + C_{res}}$

$\boldsymbol{Q_S} =$ 45.13 W/m^2

$\boldsymbol{Q_L} = E_{sk} + E_{res}$

$\boldsymbol{Q_L} =$ 15.15 W/m^2

$\boldsymbol{M} = Q_S + Q_L$

$\boldsymbol{M} =$ 60 W/m^2

varying sensible heat by physionomical characteristic

Weight in the 1. grade: a boy = 21.95 kg, a girl = 21.75 kg (mean values)

Height in the 1. grade: a boy = 118.8 cm a girl = 118.1 cm (mean values)

$\boldsymbol{A_{Du}}$: a boy = 0.85 m^2 a girl = 0.84 m^2

$\boldsymbol{Q_S (A_{Du} \times Q_S)}$: a boy = 38.43 W a girl = 38.05 W

calculating heat load levels of a classroom (S1)

Number of students = boys = 16 girls = 15 1.5 m2 per student

Sensible heat load per area = 25.44

South oriented classroom

$\boldsymbol{t_a} =$ 20 °C heated space

$\boldsymbol{t_{ext}} =$ 1.3 °C for January

$\boldsymbol{Q} = \boldsymbol{[H_s (t_a - t_{ext}) - \eta \times (\phi_i + \phi_s)] \times t}$, J, ………………………………………………………………(2.15)

where

$\boldsymbol{H_s} = \boldsymbol{H_{con} + H_v} =$ 71.63 W/K specific heat loss of classroom

$H_{con} = \sum A \times U + lU_I = 32.26$ W/K, ……………………………………………….….(2.16)

$U_{ex\_wall} = 0.44$ W/m^2 x K

$U_{ground} = 0.59$ W/m^2 x K

$U_{window} = 2.8$ W/m^2 x K

$A_{ex\_wall} = 23.04$ m2

$A_{ground} = 46.6$ m2

$A_{window} = 3$ m2

$\sum A \times U = 32.26$ W/K

$lU_I = 0$ Thermal bridge is neglected

$H_v = 0.33 \times n_v \times V_v = 39.37$ W/K, …………………………………………………(2.17)

$n_v = 1$ h^{-1}

$V_v, = 0.8 \times V_{gross} = 119.30$ m^3

$V_{gross} = 149$ m^3

$\phi_s = \sum r_i \times g_i \times I_i \times A_i = 103.68$ W, ...(2.18)

$r_i =$ 0.8 detached building

$g_i = 0.8 \times g_\perp = 0.60$

$g_\perp =$ 0.75 clear multiple glazing

$I_i =$ 72 W/m^2 south-January

$A_i =$ 3 m^2 window-south

$\phi_i = 25.44 \times A_n = 1185.96$ W

$\eta = 1\text{-}e^{(-1/GLR)} = 0.65$ utilization of gain factor, ……….…………………...………… (2.19)

$GLR = (\phi_i + \phi_s) / H(t_{in} - t_{ex}) = 0.96$

hence

$Q =$ 1821,66 kJ = 0.51 kWh heating energy need as normalized value (Q_1)

APPENDIX F

STATISTICAL RESULTS

Table F.1. The results of *t*-tests for paired samples of grades

		Mean	Std. deviation	Std. error of the mean	95% Confidence ınterval of the difference		*t*	df	Sig., 2 tailed
					Upper	Lower			
Pair 1	Grade 1 Grade 2	—	—	—	—	—	—	—	—
Pair 2	Grade 1 Grade 3	0.0133	0.0052	0.0021	0.0079	0.0188	6.325	5	0.001
Pair 3	Grade 1 Grade 4	0.0250	0.0084	0.0034	0.0162	0.0338	7.319	5	0.001
Pair 4	Grade 1 Grade 5	0.0333	0.0082	0.0033	0.0248	0.0419	10.000	5	0.000
Pair 5	Grade 1 Grade 6	0.0483	0.0117	0.0048	0.0361	0.0606	10.127	5	0.000
Pair 6	Grade 1 Grade 7	0.0533	0.0186	0.0076	0.0338	0.0729	7.016	5	0.001
Pair 7	Grade 1 Grade 8	0.0567	0.0186	0.0076	0.0371	0.0762	7.455	5	0.001
Pair 8	Grade 2 Grade 3	0.0033	0.0052	0.0021	-0.0021	0.0088	1.581	5	0.030
Pair 9	Grade 2 Grade 4	0.0150	0.0084	0.0034	0.0062	0.0238	4.392	5	0.007
Pair 10	Grade 2 Grade 5	0.0233	0.0082	0.0033	0.0148	0.0319	7.000	5	0.001
Pair 11	Grade 2 Grade 6	0.0383	0.0117	0.0048	0.0261	0.0506	8.032	5	0.000
Pair 12	Grade 2 Grade 7	0.0433	0.0186	0.0076	0.0238	0.0629	5.701	5	0.002
Pair 13	Grade 2 Grade 8	0.0467	0.0186	0.0076	0.0271	0.0662	6.139	5	0.002
Pair 14	Grade 3 Grade 4	0.0117	0.0041	0.0017	0.0074	0.0160	7.000	5	0.001
Pair 15	Grade 3 Grade 5	0.0200	0.0063	0.0026	0.0134	0.0266	7.746	5	0.001
Pair 16	Grade 3 Grade 6	0.0350	0.0105	0.0043	0.0240	0.0460	8.174	5	0.000
Pair 17	Grade 3 Grade 7	0.0400	0.0167	0.0068	0.0224	0.0576	5.855	5	0.002
Pair 18	Grade 3 Grade 8	0.0433	0.0175	0.0072	0.0250	0.0617	6.061	5	0.002
Pair 19	Grade 4 Grade 5	0.0083	0.0041	0.0017	0.00405	0.0126	5.000	5	0.004
Pair 20	Grade 4 Grade 6	0.0233	0.0082	0.0033	0.0148	0.0319	7.000	5	0.001
Pair 21	Grade 4 Grade 7	0.0283	0.0133	0.0054	0.0144	0.0423	5.222	5	0.003
Pair 22	Grade 4 Grade 8	0.0317	0.0147	0.0060	0.0162	0.0471	5.270	5	0.003
Pair 23	Grade 5 Grade 6	0.0150	0.0055	0.0022	0.0093	0.0208	6.708	5	0.001
Pair 24	Grade 5 Grade 7	0.0200	0.0110	0.0045	0.0085	0.0315	4.472	5	0.007
Pair 25	Grade 5 Grade 8	0.0233	0.0121	0.0049	0.0106	0.0360	4.719	5	0.005
Pair 26	Grade 6 Grade 7	0.0050	0.0084	0.0034	-0.0038	0.0138	1.464	5	0.038
Pair 27	Grade 6 Grade 8	0.0083	0.0075	0.0031	0.0004	0.0162	2.712	5	0.042
Pair 28	Grade 7 Grade 8	0.0033	0.0052	0.0021	-0.0021	0.0088	1.581	5	0.030
Std.: Standard; *t*: *t*- distribution; df: degrees of freedom; Sig. : Sigma									

Table F.2. The results of *t*-tests for paired samples of five heating loads

		Paired Differences					t	df	Sig. 2 tailed
		Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference				
					Upper	Lower			
Pair 1	Q_{south} - $Q_{eastwest}$	-0.0867	0.0320	0.0131	-0.1203	-0.0530	-6.625	5	0.001
Pair 2	Q_{south} - Q_{north}	-0.1367	0.0539	0.0220	-0.1933	-0.0801	-6.209	5	0.002
Pair 3	Q_{south} – Q_{21}	-0.0800	0.0109	0.0045	-0.0915	-0.0685	-17.889	5	0.000
Pair 4	Q_{south} – $Q_{U\text{-}value}$	0.0833	0.0103	0.0042	0.0725	0.0942	19.764	5	0.000

Table F.3. Descriptive statistics for five heating loads in six schools

	N	Minimum	Maximum	Mean	Std. Deviation
Q_{south}	6	0.92	1.30	1.0800	0.1270
$Q_{eastwest}$	6	0.98	1.43	1.1667	0.1554
Q_{north}	6	1.01	1.51	1.2167	0.1759
Q_{21}	6	0.99	1.40	1.1600	0.1376
$Q_{U\text{-}value}$	6	0.85	1.20	0.9967	0.1188
Valid N (listwise)	6				
N: number					

Table F.4. Descriptive statistics for all 8 grades for the six schools

	N	Minimum	Maximum	Mean	Std. Deviation
Grade 1	6	0.49	0.76	0.6000	0.09654
Grade 2	6	0.48	0.75	0.5900	0.09654
Grade 3	6	0.48	0.74	0.5867	0.09522
Grade 4	6	0.47	0.72	0.5750	0.09203
Grade 5	6	0.46	0.71	0.5667	0.09004
Grade 6	6	0.45	0.69	0.5517	0.08589
Grade 7	6	0.45	0.67	0.5467	0.07941
Grade 8	6	0.45	0.67	0.5433	0.07840
Valid N (listwise)	6				

APPENDIX G

PREDICTED DAILY BMR FOR INDIVIDUALS OR GROUPS OF INDIVIDUALS OF BOTH GENDER, ACCORDING TO DURNIN (1981).

Table G.

Infants & children			Ages 10–18 y. and over 30 kg					Adults				
	Column 1			Column 2		Column 3			Column 4		Column 5	
Wt			Wt	Boys		Girls		Wt	Men		Women	
(kg)	MJ	(kcal)	(kg)	MJ	(kcal)	MJ	(kcal)	(kg)	MJ	(kcal)	MJ	(kcal)
3	.63	150	32	5.02	1200	4.69	1120	36	-	-	4.20	1005
4	.84	200	34	5.17	1235	4.85	1160	38	4.85	1160	4.37	1045
5	1.09	260	36	5.31	1270	5.02	1200	40	5.04	1205	4.54	1085
6	1.34	320	38	5.46	1305	5.17	1235	42	5.21	1245	4.73	1130
7	1.55	370	40	5.61	1340	5.31	1270	44	5.36	1280	4.90	1170
8	1.88	450	42	5.73	1370	5.44	1300	46	5.52	1320	5.06	1210
9	2.13	510	44	5.84	1395	5.56	1330	48	5.67	1355	5.23	1250
10	2.34	560	46	5.94	1420	5.67	1355	50	5.82	1390	5.40	1290
11	2.55	610	48	6.07	1450	5.75	1375	52	5.98	1430	5.52	1320
12	2.76	660	50	6.19	1480	5.84	1395	54	6.13	1465	5.65	1350
13	2.93	700	52	6.32	1510	5.90	1410	56	6.28	1500	5.75	1375
14	3.14	750	54	6.44	1540	5.98	1430	58	6.42	1535	5.86	1400
15	3.31	790	56	6.57	1570	6.05	1445	60	6.57	1570	5.90	1425
16	3.43	820	58	6.69	1600	6.09	1455	62	6.69	1600	6.05	1445
17	3.56	850	60	6.80	1625	6.13	1465	64	6.84	1635	6.15	1470
18	3.68	880	62	6.92	1655	6.23	1490	66	6.97	1665	6.23	1490
19	3.81	910	64	7.05	1685	6.32	1510	68	7.07	1690	6.32	1510
20	3.93	940	66	7.15	1710	6.40	1530	70	7.18	1715	6.40	1530
22	4.14	990	68	7.28	1740	6.46	1545	72	7.26	1735	6.49	1550
24	4.35	1040	70	7.41	1770	6.52	1560	74	7.34	1755	6.55	1565
26	4.52	1080						76	7.43	1775	6.61	1580
28	4.67	1115						78	7.49	1790	6.67	1595
30	4.81	1150						80	7.55	1805	6.74	1610
								82	7.59	1815	6.80	1625
								84	7.66	1830	6.86	1640
								86	7.70	1840	6.90	1650
								88	7.74	1850	6.97	1665
								90	7.78	1860	7.03	1680
								92	7.82	1870	7.09	1695