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Summary of the Ph.D. thesis

Research about the energy efficiency of building glazings with attachments, in the conditions of our country

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Keywords

Chapter 1 : solar angles, Great Distance Circle Theorem, Law of Cosines, isotropic diffuse solar radiation
Chapter 2 : 2D polygon boolean operations, degenerate intersections, en,ex rule, multiple vertex, computational geometry algorithm
Chapter 3 : glazing, frame , thermal transmittance, thermal bridge, shutter, window energy balance
Chapter 4 : shading device, awning, overhang, dynamic energy simulation, cooling load
Chapter 5 : U measuring installation, exterior shutter, thermal insulation

Contents

The Thesis consists of 5 Chapters and their respective Annexes . The Chapters are self-consistent to an important extent and for that reason they can be read independently (the References are grouped by Chapter too). This very short version of the Thesis has thus 5 short descriptions, one for each Chapter. The figures selected to be shown in here have the same number as in the long version; the same is true for the selected References.

Chapter 1

In this part of the Thesis, formulae for the solar radiation beam angles valid in the case of a location in the Northen hemisphere, of latitude between the Tropical and Arctic Circles are calculated. The two spherical angles defining the direction of the solar rays are derived in a new way, that, in our opinion, is simpler than the derivations in the literature of the field.

The final result consists of the solar "elevation" and the solar "azimuth" in the specific cartesian frame of the receiving surface (that surface is in general a solar collector ; a building window is a special case of a solar collector). The receiving surface has an arbitrary cardinal orientation and inclination. But before the final result is calculated, the two mentioned angles associated to the local horizontal frame of the location in question are found out . And before that, the same pair of angles (named this time solar declination and solar-hour angle) associated to the so-called local equatorial frame is obtained.

So passing from the local equatorial frame to the specific cartesian frame of the receiving surface via the local horizontal frame of the respective location on Earth gives the time dependence of the final pair of spherical angles (the variation in time of the solar declination is derived from that of the orbital longitude angle of the Earth in the very simple assumption the Earth circularly orbits the Sun in a perfectly uniform manner).

A fundamental hypothesis used by us in the calculations is the parallelism of the solar rays reaching the Earth; their refraction through the terrestrial atmosphere has been neglected as well.

For every pass from one derivation stage to the next, The Great Circle Distance Theorem (GCDT), also known as Law Of Cosines, of the spherical trigonometry is employed. But we apply it without referring to the quite complicated spherical geometry or trigonometry and the demonstartion of the Theorem is made in Annex 1.1 in a personal, completely elementary manner that uses plane geometry.

Solar declination has been calculated in two different ways, both personal : one uses GCDT , the other uses elementary analitical geometry to find out the dyhedral angle at solar noon made by the equatorial plane and light-shadow plane (the one always normal to the generic solar ray that produces on the Earth globe surface two hemispeheres, one in day light the other in solar shadow/night darkness) .

Also, a personal derivation of the formula for the diffuse irradiance of a receiving surface arbitrarily oriented and inclined is done (in the assumption the intensity of the diffuse solar radiation coming from the sky is isotropic) .

The formulae obtained in this Chapter can be used in energy simulation software (for both whole buildings or just parts of their envelope) in the architecture or engineering fields. They are not adequate for the demanding sun-tracking field where higher precision is needed. The last derived formula, the one for the diffuse irradiance of a planar receiving surface can too be used in energy simluating software. It can be used both in a "direct" and a "reverse" way . The reverse manner implies the solar radiation leaving the back of a "surface" like a solar shade ; which is assumed to produce a perfectly isotropic transmitted "short" wave radiation .

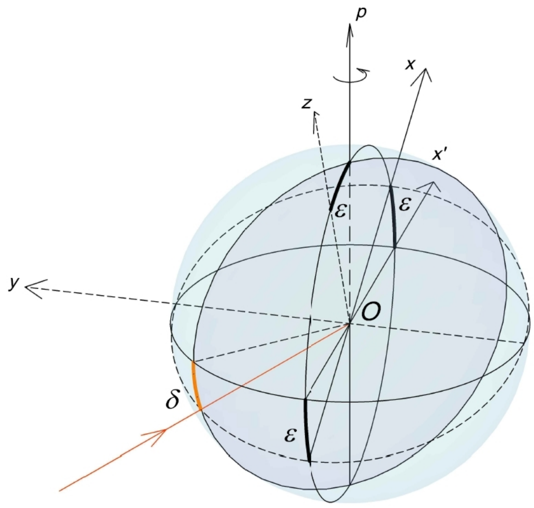


Fig. 1.1.2 The generic solar ray (that passes through the globe's center) seen from a place in space close to Earth (image used to derive the solar declination δ and the dyhedral angle between the light-shadow plane passing through O that is always perpendicular to the solar ray and the ecuatorial plane $Ox'y$ normal to Op)

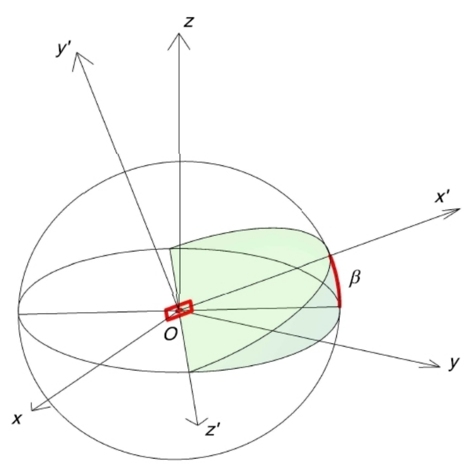


Fig. 1.5.2 Advantageous change of the cartesian frame $oxyz$ made in order to calculate the isotropic irradiance of the thick contour surface placed in the location o on Earth; the angle between the back of the receiving surface and the local horizontal plane is β so the part of the sky seen by the surface is the hemisphere above the local horizontal plane minus the "melon slice" of "thickness" β

Chapter 2

This is the largest chapter and it is about a pure computational geometry problem : an extension of the geometric foundation of an algorithm for boolean operations (like intersection, union and set difference) on polygonal regions in the plane. The word extension refers to solving the so-called degeneracy problem in a computational geometry algorithm similar to that given by Greiner & Hormann in 1998 (abbreviated further as G&H).

The issue of 2D polygon intersection and union is actually the general theoretical formulation of a very concrete enegineering problem of the field researched in this thesis : namely calculating the final/resultant shadow on a planar receiving surface when produced by various obstacles in front of it (their individual shadows on the surface, that can be a solar collector or a window, are the polygons that should be intersected or/and united) . So applying boolean operations on those shadows is the core of the shadow analysis in engineering; and that is of course done using an adequate algorithm in a special computer program.

In Chapter 2 we have tried and succeded to complete a G&H-like algo so that it is able to handle in a deterministic way the degenerate intersection situations; something of interest in many practical applications including the shadow calculation mentioned above.

We have reached the sought goal by gradually complicating the question to answer. Only the intersection operation has been dealt with but the boolean operations union and set difference can be approached similarly.

As regards the degenerate intersection situations we have discovered 2 ways to takle the problem . In one of them, when the result contour is built by assembling contour parts of the 2 input polygons (one is called clipper and the other subject), we ALWAYS choose the same polygon contour where the two input contours overlap (this method has been named by us the "fixed clipper" approach). In the second, flexibility in choosing the contour part that will be used for the result contour is allowed in the same situation (this method has been named by us the "switching clipper" approach) . By convention (observed in the whole Chapter), the clipper is always colored in red and the subject is always colored in black and in the "fixed clipper" approach the black contour is always selected for building the result contour in case of an overlap. We only describe the "fixed clipper" approach in the Thesis as in our opinion it offers a more comprehensive view than the other possible approach.

Step 1 states an answer to the following question : how should the result contour be built if, in contrast to the original G&H, the two input contours (considered non-self-intersecting in their intersection points) can exhibit degenerate cases ? Situations where the vertices of an input contour are allowed to be placed on the other input contour. The input contours/polylines are "represented" in the computer mind as enreached/completed (red and black) lists of similarly structured "multicompartment boxes" ; such a "box" standing for a vertex and each of its compartments for an attribute of that vertex (like its position in the plane or if it's an intersection vertex etc) .

An important observation in answering the question of the current step is there are two different/distinct aspects or maybe better said functions of an intersection point : the geometric place where the red and black contour intersect and the place (end of a red or black contour part) where a concatenation is made when building the bicolor result contour (which is a string of red and black parts that alternate) .

Another very important observation we made, new to our knowledge classifies the called-by-us non-trivial trials of the clipper (red)m contour to cross the subject (black) contour into 8 categories (the trivial crossing trials are the one-intersection-vertex trials whereas the non-trivial ones consist of series of at least two consecutive intersection vertices in the red or black vertex list) .

Based on the above ideas, we have stated 3 very simple Rules to select the right red concatenation vertex from the set/series of consecutive intersection vertices a successful non-trivial crossing trial of the clipper consists of . The required info to make the proper selection decision is : the position of the intersection vertex within the consecutive vertex series, the relative position of the oriented edges/arrows (2 red and 2 black) meeting in an intersection point and the location status of the 2 red arrows relative to the black polygon (inside it, outside it or on its border) .

We then discovered that breaking the policy to make the minimum number of concatenations when assembling the result contour from red and black pieces and adding a seemingly unnecessary Rule 4, the set of the selection Rules can actually be compacted in just one simple RULE for the clipper (and this RULE is extremely close to the rule used by the original G&H) .

Thus, not only the geometric basis of the extended algo is simple and elegant but its efficiency is increased too . Because now, deciding if an intersection vertex must be labeled or noat as a concatenation point needs only "local" info (related to a topological vicinity of the vertex in question), namely the "geometric type" of the red intersection vertex (*in,out* , *in,on* etc) ; its position in a consecutive intersection vertex series in the red list is no longer necessary.

Foster and Overfelt tried the same thing twice in 2012 but although at first they thought they had succeeded, it was later discovered their method gave errors in some situations, We stress that our proposal covers all possible cases where the two input contours (one red and one black) do not intersect in a self-intersection point.

Step 2 in further generalizing our approach has considered intersection points that can be self-intersections ; but self-overlaps of the (red and black) input contours are still not allowed like in the first step. In other words, now, besides 4 arrows (2 red and 2 black) intersection vertices, so called multiple vertices (in short MVs), having more than 4 arrows meeting in them, can be present .

As in step 1, we have noticed a new important distinction that is obscured in the situation dealt with by the original G&H due to their peculiarity (which favors seeing different aspects as one and the same not different) . The observation we have made is if MVs are allowed then more than just one neighboring contour part of the opposite color are possible in a concatenation point when assembling the result contour from red and black pieces . In contrast, we have had unique red and black neighbors in the bicolor result contour where all intersection vertices have 4 arrows . The consequence of that is assigning a unique pair of linked vertices (one red and one black) of the same posiition in the plane to an intersection point as we did in step 1 is no longer justified .

The concatenation recipe in the new context should reflect the mentioned flexibility: more than just one possible neighbor of opposite color in a concatenation point. Also, situations can be present where one or more neighbors of the same color are concatenated in the same point .

Another generalization refers to the concept of geometrical location relative to a polygon interior . In step 1 we exclusively handled contours of either left hand (the polygon interior is on the left of the contour) or right hand (the polygon interior is on the right of the contour) . Now also contours of both hands (interior on left and on right too) or no hand (exterior on left and right too) come into the story . This generalization was side-stepped before as only intersection of border lines, separating the polygon interior from its exterior (simple polygon contours locally) were considered .

To select the "routes" of the result contour in an input MV (in general bicolor) we propose a simple method : a circular (local) scan in the plane of that MV . The output is the red and black arrows that belong to the result . In that way, simple or multiple vertices of the result contour are found out . The suggested method is new to our knowledge .

In this phase, we also give a generalized concept for what was in step 1 the unique link between 2 vertices (one red and the other black) that have the same position in the plane (in other words that point is an intersection point); and are marked as concatenation vertices . As said before, due to the presence of input MVs it is now possible to concatenate two contour parts of the same color ; this can still be done directly, like we did on step 1 for contour parts of opposite color. But in general, it is possible to have bicolor MVs that belong to the result contour; said otherwise, more than just one black and one red piece join in the same point . So to assemble the result in such a situation, indirect jumps are used not the old direct jumps/links between the red and black (enreached) vertex lists . They are called indirect because they are via an additional list, the list of MVs that are present in the result contour and that also are concatenation points . They are named reduced MVs because some of the routes/threads/roads of them (namely those that just pass through them on and do not have a dead end there) have been cleaned out .

Reduced MVs operate like a.... connecting any two input contour parts whose one end point's position is of the respective MV . The third list that comes into play is the list of the reduced MVs and an indirect jump between two vertices, each in one monocolor list (either the same list or one in the red list and the other in the black list) is done via the reduced MVs list. The new task we face is to properly manage this third list . What is meant by that is updating it after a certain route in a certain reduced MV has just been selected to be added/concatenated to the result contour. So before jumping into the destination monocolor list, the currently used route is discarded from the set of still available routes of the MV in question (the one we are currently visiting) . That is the reason the jump is called indirect : because first we get to a certain vertex in a monocolor list (labeled there as belonging to a reduced MV) after which we jump into the reduced MVs list and "land" in that reduced MV the monocolor vertex we have just left belongs to; and there, we inspect the routes of that reduced MV still not used in the process of building/assembling the result contour. One of those routes having a dead end is then chosen and we make the final/second jump into a monocolor list (the one where the dead end of the just selected route is placed) .

In the case of simple intersection or self-intersection vertices not MVs of the result contour, where 2 arrows meet (either of the same color or of opposite color as in step1), we still use the old method of the direct jump/link .

When in every reduced MV (in the third list) every route has been used in the construction of the result contour and the current result contour has been closed the result is ready (the border of the result polygonal region an consist of just one closed contour or more than one closed contours having no common points) .

Step 3, the last, takes into account the following fact/observation : we always can redraw the border of an input polygon that has contour overlaps to get rid of those overlpas and end up with a one-hand border (not necessarily the same hand along its entire length) ; that is the new/redrawn border corectly separates the interior of the initial polygon from its exterior everywhere and no part of it has two hands or none . The mentioned redrawing can be done for a polygon filled by both the even-odd rule or by the non-zero rule .

So, we recommend preprocessing the input polygon so that every contour part of the old border having overlaps is now replaced by one route/thread of the set of routes the overlap is made of .

The new mathematical object we face is what we call the monocolor "thread/route bundle" . As we said it is suggested to replace it by one thread of it . But the hand of the replacement thread has to be the resultant hand of the whole bundle (and that results by applying the used filling rule to the bundle) . Not only do we skin a bundle to a sole thread but as regards the redrawn border we ignore any bundle whose filling status is two hands or none (in other words, we only consider further bundles separating the polygon interior from its exterior) . This is a modification of an ideea used by Klaas Holwerda in an ingenious program for 2D polygon boolean operations he coded (unfortunately he has not published a paper on that ; he however offered freely the program and some related documentation that would have been wonderful had it been more detailed) . In his program, the above discussed bundles are allowed for input polygons ; but when the result contour is built they are replaced by one thread .

In contrast to that, we propose getting rid of them early so that the border of each of the two input polygons does not have contour parts of this kind ; being instead entirely a one-thread kind . Consequently, the result contour would too be of that kind .

It is of course possible to skip the preprocessing phase and accept bundles within the border of an input polygon. But we think that creates complications in the management of the result "calculation flow" further. In that case when we encounter a bicolor bundle of an input MV, we apply the same "fixed clipper" rule and first select for the result the black sub_bundle and then just one thread of it instead of the whole sub_bundle (but its assigned hand is that of the whole sub_bundle) .

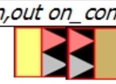
So it seems there are two avenues for resolving the input contour overlap situation :
- we preprocess the input polygons to turn them into polygons good to be handled by the method presented in step 2 (they no longer have overlapped contour parts)
- we allow overlaps of the input contours in which case the management of all the objects involved in the construction of the result contour is more complicated (in this case we have have an additional worry : to "skin" monocolor bundles encountered when assembling the result contour, bundles that are not part of a reduced MV) .

By following the above procedure we have completed what have already been incorporated in step 2 to be able do the job in the last possible complication, the presence of overlaps within the input contours .

The main ideas of step 1 have been presented ub a paper authored by R.T. Popa, E.C . Mladin, E. Petrescu and T. Prisecaru [2.58] .

Another paper that implements those ideas in a slightly different way (trying to be very close to the code in the original G&H) is going to be published by E.L. Foster, K. Hormann and R.T. Popa [2.59] .

Tabel 1. Assembling non-trivial red trials and en,ex labeling their intersection points

	No.	Trial ends		Crossing trial type	Between-ends connector type
		First end/vertex	Last end/vertex		
Name	1	*in, on_con*	*on_con, out*	*in,out on_con*	*on_con*
Lego part (symbol)					
Concatenation flag(s)		ex		ex	
Flag position				first vertex	
Name	2	*in, on_opp*	*on_opp, in*	*in,in on_opp*	*on_opp*
Lego part (symbol)					
Concatenation flag(s)		ex	en	a pair : ex, en	
Flag position				first and last vertex	

Two degenerate situations and how the intersection points of the clipper (always drawn in red) should be en,ex labeled according to the extended rule given by us in step 1

Chapter 3

In this part of the Thesis, several calculations related to thermal performance analysis of framed glazing are done . We are grateful to our colleague Eng. D. Ioana Udrea for collaborating to the work of this Chapter.

The simulation software that we have much have used here is THERM and WINDOW, both free programs offered by Lawrence Berkeley National Laboratory (LBNL), USA .

The presented calculations successfully obtained values for the energy quantity U ($W/m^2/K$) in case of the plain/unframed glazing and the framed glazing (a combination usually called window) unmounted within the building envelope) ; and in the end, for a mounted window as well .

The success of the calculation was in general judged by comparing the values obtained by us with values reported by well-known frame and window producers or testers . We have got quite close numbers to theirs despite the fact we had to guess some minor pieces of information .

For instance, when the POLITEHNICA Passivhaus was designed, the U value calculated by us for the unframed glazing (called center-of-glass U and denoted U_g) was U_g = 0.608 W/ m^2/K [3.28] ; while the glass producer Saint Gobain Glass (SGG) , using their own software, provided U_g = 0.60 W/ m^2/K .

Regarding frame U-values, the outcome of our calculation for the PVC frame model Alphaline 90 manufactured by Veka is U_f = = 1.12 $W/m^2/K$ [3.42] (that in the conditions our info about the frame materials was not complete) ; a manager from Veka gave U_f = 1.1 W/ m^2/K [3.23] at a 2007 Conference in Bucharest .

U_f =1.68 W/m^2/K [3.42, 3.43] is what we calculated for the (good performance in its own class) aluminum frame CS-86, manufactufred by Reynaers (again our info about the frame materials was incomplete) . In a material received by us from the company that sells Reynaers products, the given simulated value is U_f =1.78 W/m^2/K .

In the POLITEHNICA passivhaus design process, for the PVC frame model Geneo MD manufactured by Rehau (a very performant frame, labeled as passivhaus frame by the Passivhaus Institut in Darmstadt), the value in a performance certificate issued by IFT Rosenheim GmbH is U_f = 0.85 W/m^2/K . Our value was U_f = 0.83 W/m^2/K (this time too, we missed some minor pieces of information about the materials the frame is made of) .

Romanian building designers seem to know very little or nothing about the importance of the thermal bridge created when mounting a window in the surrounding envelope (be it wall or roof) . That thermal bridge can considerably lower the energy performance of the unmounted window . We did numerous calculations of the said effect for various mounting detalils of aluminum and PVC frame windows (what we actualy used were two simplified structure frames that thermaly approximate the two already mentioned frames, Alphaline 90 and CS-86) . Our results are part of the Annex K of the Romanian Building Code C-107/3 issued by the Ministry for Regional Development and Tourism as the order no. 1590/24.08.2012 [3.39] .

We had to use simplified structure frames in the calculations in order to complete the whole number of required simulations in the assigned time interval (an impossible task if the real frames had been used instead due to the laborious nature of the activity, a feature of today computation technology well-known to simulationists) .

So we invented a simpler replacement of the real frame on that ocassion, the so-called thermally equivalent frame . The thermal equivalence condition is about an equal heat flow through the perimeter strip that includes both the frame and the neighboring glazing, for both the unmounted real frame window and its equivalent frame replacement . The thermal conductivity of the homogeneous material inside the simplified (no internal structure) frame results from the equality of the two heat flows .

That physical quantity is λ^{echiv_PVC} = 0.13 W/m/K for the replacement of the PVC frame Alphaline 90 and $\lambda^{Al\_2\ echiv}$ =0.19 W/m/K for the substitute of the aluminum frame CS-86 [3.42, 3.43] .

Replacing the real frame by its calculated substitute si more successful when the surrounding envelope (wall or roof) is less insulated thermally . That has been in line with our intuitive expectation being a known thing a requirement whithin a passivhaus design process is to simulate window-wall junctions in the most possible detailed way (using the real frame not some simplified version of it) .

The frame substitution recipe we proposed before producing the Thermal Bridge Catalogue of C-107/3 was something new to our knowledge .

Chapter 3 ends with another calculation involving a window attachment, an exterior insulated shutter (an envelope part apparently quite popular in the German language countries) . Today, that is something very rare in the Romanian building landscape . We did the monthly energy balance for a South-oriented window in Bucharest, completely exposed to the solar radiation during daylight time and having its shutter completely closed at night . Two choices for the window shutter have been made, a plain wood shutter 1 cm thick and an insulated version of the previous, the thermal insulation being 3 cm thick . Obviously, such a thickness possibly excludes roll shutters, requiring some sort of a one-piece panel shutter that is hinged or glides on some rails in a plane parallel to the building wall .

The whole calculation has deliberately been made in a very simple manner to very clearly underline the role of the thermal properties of the 4 considered windows (2 having "red" glazing and the other 2 "green" glazing, that is low heat losses through it at night) . we used again WINDOW and THERM to compute in all 4 cases the thermal transmittance of the uninstalled window, $U_{w,uninstalled}$ ($W/m^2/K$), with and without shutter.

Just one value was produced for each of the 6 cold months for both the window heat losses and its solar gains, obtained considering steady-state behavior . The climate data used were the monthly means for the air temperature and the total solar radiation on a surface facing South in Bucharest (from October through March) .

The 4 windows have all the same performant PVC frame, Alpahline 90 made by Veka . The 4 different glazings were chosen to encompass a quite large range for the heat losses and solar gains through the window . One extreme of the covered interval is large heat losses and large gains too ; the other is small heat losses but also not very large solar gains . The two glazings of the first extreme have been named the "red" glazings and the other two, of the second extreme, the "green" glazings (they are low_glazings and because of that their U_g is low, in contrast to the first pair) .

The assumed shutter strategy has been as follows : shutters completely closed at night and completely opened during daylight time (so that the entire available solar radiation is collected by the window) .

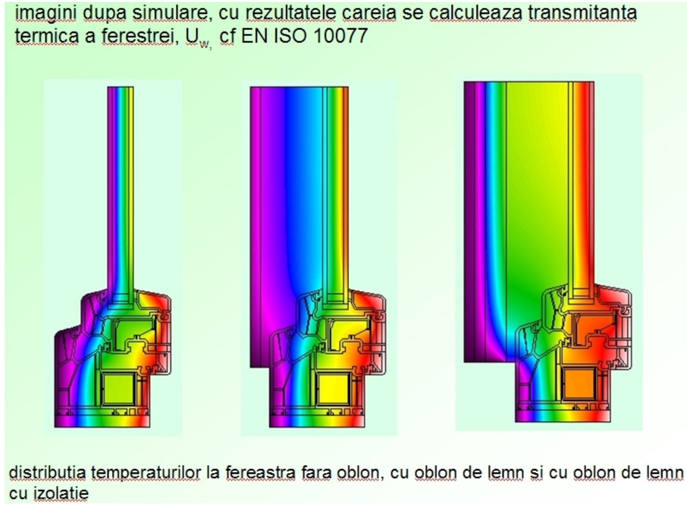
For a given glazing, the window energy balance terms (losses and gains) have been compared for 3 cases : window without shutter at night, window with the plain wood shutter at night and window with the insulated shutter at night . During the daylight time, all the previous cases are identical : window totally exposed to solar radiation (no shutter) .

The thermal bridge correction for mounting/installing the window on the wall has been included in the window energy balance . The psi_installation value has been chosen so that the energy balance (also called net energy loss) is approximately zero even in the most unfavorable months (December and January) . Subsequently, we looked up that zero balance matching value in the Thermal Bridge Catalogue to evaluate if it was realistic, if it could be attained in practice .

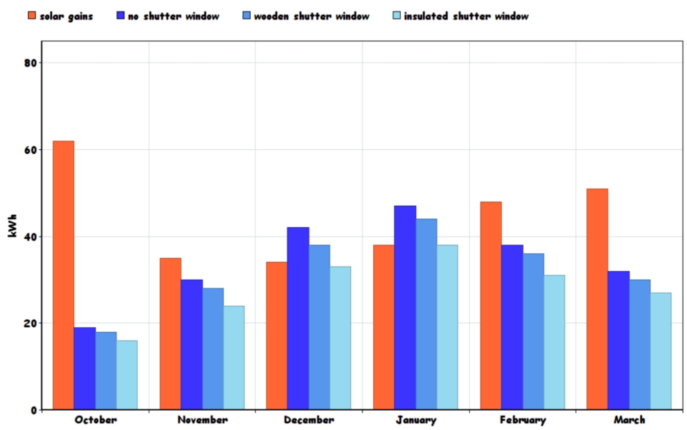
Our conclusion (that we have not found in the literature) was positive : providing South-facing windows in Bucharest with consistently insulated shutters completely closed at night and completely opened during the day is an energy efficient strategy .

If such a window collects the entire solar radiation available (no obstacle produces a shadow on it) and has a good frame and a good installation thermal bridge design and execution, does not have net monthly energy losses even in the coldest months of the year. The calculation results for the first "red" and "green" windows have been presented at the 2013 SPERIN Conference [3.33] . Those for the second pair (the "green" glazing of this pair is the one used in the experiment of Chapter 5) have been presented at 2017 TE-RE-RD International Conference [3.34] .

We also mention here the opaque envelope thermal bridge corrections we calculated as part of the POLITEHNICA Passivhaus design [3.28] that were then sent for approval to the Passivhaus Institut in Darmstadt [3.31] and they okayed those calcs . Some of them have been presented at the 2017 CIEM Internal Conference, held in Bucharest [3.54] .



Temperature field results of the simulation in THERM of LBNL for the window without shutter, with wood shutter and insulated shutter (above). The obtained thermal transmittances were further used to calculate the monthly energy balance of the window (below)



Chapter 4

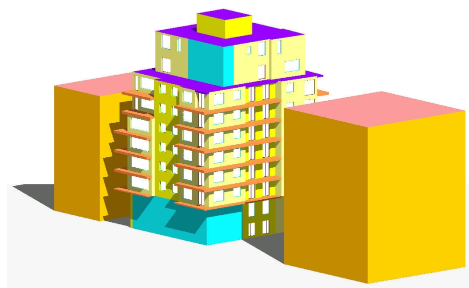
In the first part of this chapter we have analysed a classical setup for a vey simple shading situation : a South-oriented facade provided with overhang or awning . We again thank our coleague D. Eng. Ioana Udrea for her collaborating with us in the work for the current chapter .

The second, lenghter part of the chapter is about a dynamic (hourly) simulation for a 13 floor mixed (office-residential) building in Bucharest . Of the 13 floors, 3 are undergorund (and used as parking lot) . The building envelope insulation is quite good . The simulation extended over 11 consecutive summer days and the purpose was to asses the effect on the cooling load produced by some exterior shades made whose solar opacity is quite high (the shades were considered on during the solar day) . The simulation was done in TAS during the free trial period offered by the software owner, Environmental Design Solutions Limited (EDSL) .

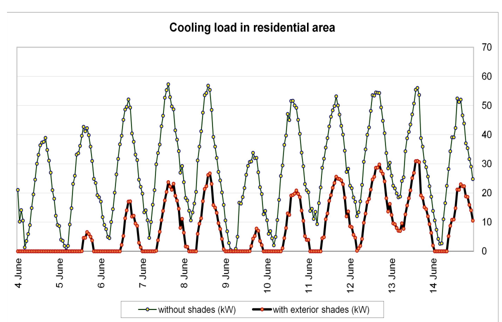
The results plead for the energy efficiency of using such shading devices : the solar gains decrease spectacularly and the cooling load goes down too although not as strongly . It is more than obvious smaller size heating equipment could be used in combination with the shades .

We suggest the provision in the Romanian building codes to require assessing the effect of exterior shading devices before the execution phase of a building . They are not expensive and very versatile . But their energy efficiency should be considered in the design phase because installing them after the envelope has been built lowers the number of possible options and may interphere with building structure or aesthetics . Doing that after design can many times result in undesired impairment of various other functions of the building envelope (like for instance being a hydro barrier or a thermal one) .

Results of the above work have been presented at the 2017 CIEM Internal Conference, held in Bucharest [4.37] .



The simulated building (center) and its cooling loads for the residential area (floors from third above included) which is non-stop conditioned (red with and black without shades)



Chapter 5

This last chapter, the experimental part of the Thesis, has an unambiguous conclusion : it is energy efficient to have consistently insulated exterior shutters attached to windows in Bucharest and in general in much of the Romanian climate and close those shutters during cold nights .

By using a very simple "differential" experimental installation, built by us from scratch, we conservatively evaluated the heat losses through the glazing at night had been reduced by 30% due to an exterior shutter made from EPS 3 cm thick (the tested glazing, provided by Saint Gobain Glass Romania as a U_g = 1.1 W/m^2/K IGU, was low-e with a 90% Argon & 10% Air in the interlayer cavity) .

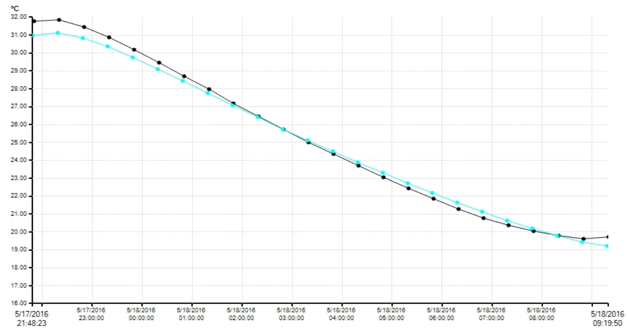
A triple pane glazing, having a passivhaus U_g = 0.6 W/m^2/K according to SGG's own calculations, has also been tested (the unit had 2 low-e glass layers and both cavities were filled with the previous gas mix) . The conclusion is this time, the decrease in the heat losses is too small to justify adding the very thick thermal insulation in the experiment (more than 5cm) to a plain shutter (made for example from wood or plastic) .

In general when having such an excellent U_g glazing, plain shutters (without insulation) can be recommended for the occupants' comfort . They still increase a little the outside face temperature of the glazing and consequently its inside temperature too (by increasing the thermal resistance through the exterior air film at the window surface especially when the wind is strong) .

The extremely simple experimental equipment was intended to replace the classical hot box (where the temperatures of the two environments the glazing is in contact with are precisely controlled and kept constant) . It consists of two identical OSB boxes having their long axis horizontal and a square cross-section (45cm x 45cm) covered by the tested glazing . The boxes were insulated on their outside with EPS 10cm thick and placed outdoors, on the rooftoop of the Faculty building. The precision of the used setup is way too low to qualify for rating various glazings but the difference in the tested cases (triple and double glazing with and without shutter at night) has been very clear and the drawn conclusion is firm . The experimental installation is very easy-to-built but its outdoor location restricts the time interval for reasonable measurements to meteorogical calm spring or fall nights, without rain or wind and having monotonically outside temperature variation .

The 2 experimental boxes on the roof top of the Faculty of Mechanics and Mechatronics Building

Fig. 5.2.2.18 Below, the night temp recording of 17-18 May 2016 (black, the box without shutter, cyan the box with insulation shutter) ; estimated heat flow is derived from it



Selected References

2.58 R.T. Popa, E.C. Mladin, E. Petrescu, T. Prisecaru, A simple en,ex marking rule for degenerate intersection points in 2D polygon clipping, downloadable https://arxiv.org/abs/1709.00184

2.59 E.L. Foster, K. Hormann & R.T. Popa, urmeaza sa fie trimisa spre publicare

3.28 Contract UAUIM nr. 23/2008 al Proiectului "Case pasive adaptate conditiilor climatice din Romania" din cadrul Programul National de cercetare-inovare PN II 2008, proiect confinantat de MEC, coordonator si Cofinantator SC ISPE SA cu parteneri : UPB, UAUIM Buc, UTCB, ICPE (cofinantator), AOSR, AGECOM Baia Mare (cofinantator)

3.39 Anexa K la Ordinul 1590/24.08.12 pt modificarea C 107/3, Catalog cu punti termice specifice cladirilor

3.42 Studiu preliminar echivalare toc in cadrul Contractului UAUIM cu MDRT , 2010 , pentru elaborarea unui Catalog Punti Termice pentru Cladiri, Anexa a normativului C 107/3

3.43 Georgescu M.S., Udrea I., Popa R. & Andone R., Testare exploratorie a inlocuirii in detaliile de montaj fereastra a unui toc real din PVC cu un toc fara structura interioara, echivalent, Conferinta Nationala a Asociatiei Auditorilor Energetici pentru Cladiri, Craiova 2012

3.54 Ioana Udrea, Romeo Traian Popa, Emilia-Cerna Mladin, Mihaela-Stela Georgescu, Cristina Victoria Ochinciuc, Thermal bridges evaluation for a Passive House building in Romanian Southern climate, 2017 International Conference on ENERGY and ENVIRONMENT (CIEM), Bucharest, 19-20 Oct. 2017, Publication Year 2017, Page(s):456 - 459, downloadable http://ieeexplore.ieee.org/document/8120822/

4.37 Ioana Udrea, Romeo Traian Popa, Exterior shades energy efficiency for a mixt, office-residential building in Bucharest, 2017 International Conference on ENERGY and ENVIRONMENT (CIEM), Bucharest, 19-20 Oct. 2017, downloadable http://ieeexplore.ieee.org/document/8120823/